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THE STORY OF AIDS TO NAVIGATION

BY

THOMAS COULSON[1]

"There be three things too wonderful for me, yea, four which I know not: the way of an eagle in the air; the way of a serpent on a rock; the way of a ship in the midst of the sea; and the way of a man with a maid."

When the wise Solomon put the way of a ship in the category of things beyond his comprehension he must have been pondering over the tales of those seafarers who had brought the gold and ivory, the apes and the peacocks from far distant lands to adorn the great king's court. Their tales of finding a way over the trackless waters must have savored of necromancy to the landsman. His wonderment must be shared by every reflective person who has given thought to that magic.

The science of navigation has advanced to that stage of refinement, with mechanical aids and complex apparatus, that we are prone to forget there was a time when men sailed over wide stretches of ocean without aid from any of these devices. Vessels were accustomed to travel over rivers, inland seas, and short coast-wise voyages long before they deliberately ventured out of sight of land. But the time arrived when the traders of Asia and the bold islanders of Polynesia took advantage of the monsoons to travel across the Indian Ocean and the China Sea without benefit of instruments. We have no written record of these voyages and we can only surmise at the methods adopted by the pilots.

Coming to recorded history, we find the Arabs, the Phoenicians, and other Mediterranean nations engaged in a lively intercourse, both for peace and for war, which must have taken their vessels out of sight of land for short periods. The hardy sea-rovers of the North developed a means of finding their way over the sea and back to their home ports.

[1] Director of Museum Research, The Franklin Institute, Philadelphia, Pa.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

From the very earliest records of these voyages and from later contributions to our knowledge of the sea, we catch glimpses of their navigational methods. It should be remembered that the sights of nature would be observed even more closely in those days than they are by the modern mariner, because they were the principal aids to following a course.

The stars were used by the early navigators to guide them on their courses. There are many references in classic literature to the use of stars as aids in navigation, as in that passage in the *Odyssey* where Homer writes: "The Bear which they likewise call the Wain, which turneth ever in one place and keepeth watch upon Orion, and alone hath no part in the baths of ocean. This star Calypso the fair goddess bade him keep ever on the left as he traversed the deep," when Ulysses departed from her island home. A less known but more significant passage relating to the practice of holding a certain star on the rigging, not unknown to helmsmen today, occurs in Lucan's *Pharsalia:* "Here always the Lesser Bear . . . stands on the ropes of the main yard; then do we look towards the Bosphorus."

Quotations on the subject could be multiplied, and quite naturally, for astronomy was the first of the sciences to be developed. The sky and celestial phenomena were more closely observed by the ordinary man in those days, and a knowledge of the stars, visible to the unaided eye, was more widespread than it now is.

Another aid to navigation was the study of the flight of birds, especially in their migrations. Then, we have authentic records of the use of shore-sighting birds which, when released, made their way to land, in the manner of Noah's dove. An early mention of birds being employed for navigation purposes occurs in the *Landnamabok* (Book of the Colonization of Iceland). Describing the start of Floki's voyage from the Shetland Islands to Iceland, it says: "Floki, son of Vilgerd, instituted a great sacrifice and consecrated three ravens which would show him the way; for at the time no man sailing the seas had lodestones up in the northern lands." A few days out from the Shetlands, one of the ravens was released and, after circling, saw the land astern and flew toward it. Floki then had a back bearing on his point of departure. Several days later, another bird was released but, as it failed to sight land, it returned to the ship. At the third attempt, the bird took a forward course and led them to land.

The sea-ravens of Viking times were the Cormorants or Shags of today. The Frigate or "Man-of-war" bird has been used by the Polynesians as a shore-sighting bird.

When the great voyages of Columbus' time are studied, it is seen that the navigators had many visual indications of the near proximity of land. Those navigators used acutely developed senses to discern cloud formations, the color of the water, turbulences caused by land

configuration, etc., to aid them. They learned to sniff the breeze and to interpret it to read the message it conveyed. It was only by cultivating his senses and utilizing his instincts that man learned how to overcome the immense difficulties involved in conquering the waste of waters. The literature of Greece and Rome contains frequent expressions of the awe in which the ancients held the unknown sea, and the dread with which they approached a voyage. As a picture to be looked upon from a comfortable place on shore, the sea was a thing of beauty, but to be compelled to trust one's self on a long voyage was a misfortune from which they shrank. "The flung spray and the blown spume, and the sea-gulls crying," had little allure to them. "Heart of oak and triple bronze had he who first committed his frail craft to the savage sea," wrote Horace, in admiring tribute.

There are three things essential to safe and comfortable navigation on the high seas, according to John Davis, who says in his *Seaman's Secrets*, published in the year 1607: "the Sea Compasse, Chart, and Crosse staffe are instruments sufficient for the seaman's use." The equipment of the modern ship has grown considerably more varied and complex than this, but the coastal vessel creeping cautiously from port to port, and rarely out of sight of land, had no need of instruments. Once the mariner pointed the prow of his ship into the open sea with intention of remaining out of sight of land, he had need of more than instinct and observation of nature to enable him to find his way back to port. In the time Davis wrote, the compass, chart, and cross staff were the essential instruments, but as man's knowledge increased he made use of whatever instruments the state of his civilization provided for ease of mind and safety.

The sea remains unalterable and unimpressionable, its capacity for service neither increases nor diminishes. We are still, with all our modern equipment, unable to whistle up a breeze or to quell the turbulence created by a gale. But in many other respects, great advances have been made in the manner by which man has found his way from one point to another on the surface of the globe. In the growth of knowledge there has been a natural progress in navigation, extremely slow in some periods and fast in others, in the development of the mariner's methods of following the sea's highways and byways. It is this development we now propose to follow, piece by piece. Stand by to get under way!

CHARTS

A chart is the representation on paper of a portion of the navigable waters of the world. Since most of our early records of sea voyaging are based upon records relating to navigation in the Mediterranean Sea, it is but natural that our earliest charts should relate to this tract of water. The explanation that we have no earlier charts resides in the

simple fact that earlier navigators had no need for position finding, they cruised within constant sight of land. We do not learn of them ever having found use for the sun, moon, and stars except to steer by them to maintain direction. They felt their way from port to port, and for this purpose required nothing but the simplest "sailing directions." These were contained in a *periplus*. The word signifies a voyage, or a "sailing around," and came to be applied to the book containing distances between ports, directions how to reach other harbors, dangers that lay in between, and other matters of interest to the mariner.

The *periplus* was the ancestor of our current *Coast Pilot*. Although there are many intervening steps there has been remarkably little change in either purpose or method, even the language employed is akin.

The "sailing around" books may very well have been supplemented by crude charts (although it is right to say that none has come down to us) since map-making for land purposes had already begun. Long before the time of Herodotus, the first real historian, maps of a sort were in use, for he speaks of a map of the world being made in Greece. The first actual sea charts, attributed to Marinus of Tyre, date from the first century of the Christian era. They were probably compiled from fragments of information furnished by mariners. Claudius Ptolemy discussed them, and adopted their system of projection for his better known land maps.

The method of nautical chart making was little better than the graphic presentation of notes compiled by shipmasters for their own use. The result could have been a fairly large scale chart of a short section of coast produced from the notes of men who required a considerable degree of accuracy in their information. The reports of more casual travellers were valueless to men whose lives and wealth depended upon their safe navigation. So few copies of this type of chart have survived that it is doubtful whether the making of large scale maps was a general practice.

An impenetrable mist conceals the methods adopted by the map-makers of the Dark Ages, but that some progress was made seems clear from the next type of chart we encounter. These charts were drawn to illustrate the "sailing around" books and, while the earlier ones are not accurate, they attained a degree of excellence in ornamentation which shows a genuine improvement in draftsmanship. Color was introduced with fine effect.

Portolan charts, as these were called, reached their peak of delicate drawing and rich ornamentation during the fifteenth and sixteenth centuries. They may not compare in minute exactness with the charts of today, but they are works of art that give a greater joy to the observer. Networks of fine lines drawn in colored inks radiate in the direction of the principal winds from various centers, known as

"wind roses." The principal, half, and quarter winds each had an individual color, and many another gracious note of color was added by the map-maker. It might be noted that these "wind roses" reappear on the cards of the early compasses.

The portolan charts were the maps used by the great explorers. Naturally, they were of no great assistance to the explorer who sailed an unknown sea to new lands. But the importance to which map making had arisen is reflected in the promptitude with which newly discovered countries appeared on published maps. There was as yet no improvement embodied in the compilation or projection of these maps over those of more ancient times. Care was devoted to greater accuracy in regard to distances, but every map was still a representation of the earth as a plane surface, ignoring the fact that it was, in reality, a sphere.

It was a strange world in which the early navigator found himself. A universe of phantoms floated around medieval Europe in which that continent saw itself as a small oasis, where life was normal, while mystery and magic veiled everything beyond.

To the west surged the ocean which no man had crossed, enigmatic and impassable as infinity; to the east and south all trailed away into the outer dark. The earth went on, men knew, but none could say just how. Strange stories filtered through from time to time like echoes from another planet, strange apparitions broke through the wall of ignorance, as when a man of an unknown race from the world's end was seen on the confines of Christendom, or else some greatly daring traveller went into the shades and disappeared.

The Crusades served to raise a corner of the veil. The crusaders touched the fringe of the unknown, heard and saw many new things. Thus Europe was made aware of Far Cathay, the Old Man of the Mountains, and Prester John, the Christian king who ruled a heathen continent. When medieval dreams gave place to the pursuit of facts, men set out to seek reality.

A prince of Portugal led the way. Henry the Navigator stood between two worlds—the dying Middle Ages and the dawn of the Renaissance. He was a crusader and man of science rolled into one. He established himself on the Cape of Sarges, the last point in Europe, where the Mediterranean Sea and the Great Ocean met, and set himself to solve the riddle of finding the way to India.

Dom Henry surrounded himself with mathematicians, astronomers, cartographers, makers of precision instruments, and builders of ships, collected from far and wide. With the men of theory came men of action, seamen, pilots, and adventurers out to see the world and to seek a fortune. Continually, he sent forth ships with orders to sail farther and farther south until they found the end of Africa.

They sailed cautiously at first, but soon with reckless ease when they found that the seas did not boil at the tropics, as those who were supposed to know affirmed they did. When they learned they could not sail home again against the current which swept down the coast, they did not hesitate to sail out of sight of land by making a wide sweep out into the ocean.

Thus, the Great Ocean began to lose its terrors for Henry's navigators. Not only did they build forts and trading posts along the African coast, but their caravels learned to sweep wider and wider toward the unknown west. Whether they reached the Antilles forty years in advance of Columbus, or Brazil fifty years before Cabral, is a question historians are still debating.

When Prince Henry died in 1460 the problems he had set himself were yet partially unsolved. The dream of a sea route to India had not been substantiated, but he had changed the world. He had swept away the phantoms with which men's minds peopled the Atlantic; the terror of the ocean had passed. No longer was a sea voyage a haphazard adventure, but a problem to be worked out by the rules of exact science. As a result, the world wore a wholly different aspect to the map-maker.

The mapping of the American continent proceeded as the successors of Columbus exploited his discovery of the new continent. Most of them started under the impression that somewhere west of Europe was a short cut to the treasures of the East, and they were not surprised to find islands in the ocean. For land had been represented on their maps and globes before Columbus' time. The existence of these islands had no foundation in recorded fact, but were remnants of ancient beliefs that mythical islands, like Atlantis, were located in the oceans. Having once found America, it was not long before the explorers realized the new lands formed a great continent dividing two oceans.

The idea had not taken root when the name America first appeared on a map published by Martin Waldseemuller in 1507. Waldseemuller was a theoretical map-maker, not a traveller, and he constructed his map from the dubious accounts of Amerigo Vespucci's travels. The map-maker himself evidently came to doubt the authenticity of Amerigo's claim to fame, for he changed the name of the new land to Terra Incognita in his map of 1513, but it was too late to change the habits of a people who had come to designate the land by the name bestowed upon it by a map-maker of high repute, and America it remained.

Balboa added considerably to knowledge of the mainland and was the first white man to obtain a glimpse of the Pacific Ocean from the American side, but it was not until Magellan made his famous voyage in 1520–1521 down the east coast of South America, through the Straits which now bear his name, and out into the Pacific Ocean, that the truth came to light that a great continental barrier lay athwart the way to

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the Orient. Magellan died on the voyage, but a handful of his followers pushed across the ocean and, after terrible hardships, rounded the Cape of Good Hope to complete the first circumnavigation of the globe.

From this time onward it became a matter of filling in the detail of the maps of the world, a task which is not entirely completed. A new difficulty arose in presenting the curved surface of the globe on a flat piece of paper. Even at this very early stage, dissatisfaction was expressed at the errors which arose from this difficulty, and suggestions were being advanced for their remedy. The method of "great circle" sailing, that is following the shortest distance between two points on a spherical surface, was being practiced. Great circle sailing is like following the line of vision were it possible to see the point of destination. Because the surface of the earth is curved, it is necessary to change constantly the compass course. On a Mercator chart a great circle course must be shown by a compensated curved line. This commonplace of modern navigation and the deficiencies of the portolan charts to encourage its application were set forth in print by Pedro Nunes in a treatise on the sphere published in 1537.

The defects in the majority of charts were not grave because the areas they covered were small, and the errors were proportionately trifling, but when it became necessary to find space on a relatively small map for a representation of the expanded world, the errors became serious.

Sailors and scholars who were conscious of the existing defects were unable to advance an immediate remedy. Their problem was to flatten a portion of the earth's spherical surface in a plane, to level it out so that the parallels and meridians would retain their correct relationships. In the year 1569, Gerhardus Mercator made an attempt to overcome the difficulty when he published his map of the world for the use of navigators, which was thought to provide a happy solution to the problem.

Mercator's method of projection was to conceive of the world globe as expanded on the inner surface of a cylinder. The parallels fell into place as horizontal lines and the meridians crossed them vertically at right angles. When the cylinder was flattened out (as one opens a roll of paper) it was laid in a rectangular plane. The distances and proportions near the equator are correct, but the earth's surface north and south of the equator is progressively distorted as one nears the poles. These charts will be recognized by the straight meridians which, if prolonged, will not meet, when, in fact, all meridians meet at the poles.

Thirty years after Mercator published his map of the world which, by the way, did not at first appeal to mariners, an English mathematician named Edward Wright came forward with a set of rules and tables to be applied in an improved construction of Mercator's projection for the correction of some errors. With Wright's work, the task of modern chart making had begun.

Later efforts to arrive at strict accuracy have related to stretching the map over a cone instead of a cylinder. This form of projection is used mostly for representations of continents and smaller areas because some parts of the globe can be shown in conic projection with relatively small distortion. Variations of the conic projection have been advanced, notably the polyconic (many cones) method which was employed by the International Map Committee in 1909, for the construction of their map of the world. The method adopted by the Coast and Geodetic Survey of the United States is known as the Lambert Conformal Conic Projection. Essentially, this consists of small sectional maps and information derived from aeronautical surveys being fitted together in one large map.

The modern nautical chart bears much information of interest to the mariner, such as depth soundings, lighthouse locations, permanent buoy positions, etc., in addition to topographical information. All small but important corrections occurring subsequent to the date of publication are issued in the *Notice to Mariners*, and should be entered by hand upon the chart immediatley after receipt of the notification.

The accuracy of these charts is proverbial, as Hillaire Belloc affirms when he writes: "I pick up my charts, I read my various 'Pilots' . . . and the truth comes out, august, white-robed, with level brows, contemptuous of advocacy. The documents of this great Department please me like the Creed. Their level voice is the voice of doom."

SOUNDINGS

Although the modern charts give information relating to soundings, no navigating officer would be held guiltless in the grounding of his ship unless he nad been taking frequent soundings. A knowledge of the depth of water under the keel of the ship is a necessity to safe navigation when moving into or out of port, or when approaching an anchorage, shoal water, etc.

Lead and line were used for this purpose at a very early date, as we know from references in Herodotus and the Bible (*Acts*, xxvii, 29). The soundings taken up to the time of the Great Voyagers rarely exceed two hundred fathoms. The apparatus used was a simple weight on the end of a line. As navigation began to expand, many ingenious minds were applied to the problem of making deeper soundings and of escaping the arduous task of hauling in the heavy weight after taking a reading. One of the devices produced was a weight without a line which detached a float when it reached bottom. It was proposed to calculate the depth of the water by measuring the time required for the float to reach the surface.

The first deep sea soundings were not made until 1773, when a depth of 683 fathoms[2] was recorded in the Norwegian Sea, but thereafter

[2] A fathom is six feet.

Polar explorers were conspicuous for their efforts to make deep soundings. A great impetus was given to this form of deep sea investigation by Captain Mathew Fontaine Maury, U. S. N., who is regarded as the father of oceanography.

Depth of water is not the only information furnished by the lead. As Kipling's Dan, in *Captains Courageous*, said: "'taint soundin's dad wants. Its samples. Grease her up good, Harve." Harvey followed his instructions by putting a plentiful supply of tallow in the shallow cup on the end of the lead. This enabled him to draw up sand, shell, or whatever might be on the sea bed. Disko carefully fingered and smelled the product before giving his judgment upon the vessel's location.

The end of the lead is hollowed to form a cup into which is variously placed tallow, heavy grease, or yellow soap. The original purpose was to enable the seaman heaving the lead to determine that it had actually touched bottom. The nature of the material clinging to the grease reveals the character of the sea's bottom at that point. Sailors acquire such familiarity with what the lead recovers that those on an often repeated voyage will know their location and plan their next moves like a blindfolded chess player.

The hand lead is still indispensable on many merchant ships up to twenty fathoms. It is simply a narrow block of lead weighing from seven to fourteen pounds attached to a marked line. The line is not always marked in the same fashion but the commonest way is to mark it at 2, 3, 5, 7, 10, 13, 15, 17, 20, and every subsequent five fathoms. The marks are unique. They consist of two strips of leather, three strips of leather, a white rag, a red rag, a leather with a hole in it to mark the depths up to ten fathoms. Those for 13, 15, and 17 fathoms are the same as for 3, 5, and 7, but from twenty fathoms on the line is marked by short pieces of line with knots in it.

For greater accuracy in shoal water or when surveying, a line marked in feet is used.

Several quaint calls and actions arise from the heaving of the lead. It is customary to report a sounding which agrees with one of the fathom markers with the call: "By the mark three, or five, etc." and from the common call in the shallow waters of the Mississippi, "Mark Twain," our popular novelist, took his pen name.

The deep sea (or "dipsey") lead, usually weighing thirty to one hundred pounds, is handled in similar fashion, except that it is too heavy to be manipulated by a single man. Instead, the lead is dropped from the bow, and men are stationed at intervals along the deck, each with ten or twenty fathoms of a continuous rope coiled in his hand. If the lead has not touched bottom when the sailor's rope has paid out, he calls the traditional "Watch-o-watch" as he abandons the rope to the next man in line. The sailor who feels the rope slacken as the lead

touches bottom reports the sounding. All hands then turn to the arduous task of hauling in the lump of lead and its heavy line.

The deep sea lead has been largely replaced by the sounding machine, of which there are several types. Nearly all are designed to make use of the principle that water pressures increase with depth at a regular rate. The lead, weighing twenty-five to fifty pounds, has a long thin hollow handle which acts as a protection for a glass tube, open at one end. The glass tube may be ground glass or ordinary glass with an inner coating of chemicals. Either tube will discolor to indicate the height to which the water rose within the tube, and from this indication of pressure, the depth may be calculated.

This lead and its tube are lowered at the end of a long piano wire coiled on a reel, operated by hand or by a small electric motor. A dial on the reel shows the amount of wire which has been paid out, and this record is used to check the depth indicated by the glass tube. Records made with the sounding machine are frequently liable to a considerable margin of error when the ship is underway or when other conditions are unfavorable.

The most efficient type of depth sounding device is the Fathometer which is based upon the length of time required by sound to travel through water. This instrument comprises three essential elements: (1) an oscillator to produce the sound, (2) a hydrophone for receiving the echo, and (3) a suitable device for measuring the interval between the emission of the sound and receipt of the echo, thereby indicating the distance the sound has travelled.

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In general these instruments emit a sound near the keel. The sound wave travels vertically down until it strikes the bottom and is reflected. It is picked up on its return by the hydrophone, located in the skin of the ship, and the time elapsed between emission and reception is measured. As sound travels 4800 feet per second in salt water at 60° F., half the distance travelled by the sound wave (which is water depth) can easily be calculated automatically in the instrument. The instruments vary in their manner of recording depth. All show the soundings by light flashes on a dial, and some keep a permanent record on a strip chart.

These echo sounding machines possess distinct advantages over all other methods of measuring the depth of water because they give instantaneous readings, and measurements can be made as frequently as the navigator desires. The most striking instance of their accuracy was in locating the wrecked *Lusitania*. One type of instrument is so sensitive that it is claimed it can be used in locating the depths of shoals of fish.

Buoys

Although buoys are not used for soundings, they are so frequently used in navigation to indicate a safe channel that they are dealt with

here for want of a better place. Buoys are used for a variety of purposes along the coasts and in harbors. In the United States, on approaching a channel from seaward, red buoys are held on the starboard hand in passing, and black buoys mark the port side of the channel. As a rule, starboard buoys are nuns (conical) and port buoys are cans (cylindrical).

Buoys painted with horizontal bands of black and red mark obstructions; those with black and white perpendicular stripes mark the center of the channel and must be passed closeby in order to avoid danger. Light buoys mark both sides of a channel, or a danger off the coast. Red lights mark the right hand (starboard) side of the channel; white lights mark the port (left) side. Spar buoys may take the place of either nuns or cans. Whistling or bell buoys are usually placed at the entrance of a channel or off the coast. White buoys mark anchorages.

THE COMPASS

Although it is generally supposed that the nautical compass was one of China's many contributions to the benefit of mankind, this attribution of its original source is now being disputed. Historians of science appear unable to affirm definitely by whom and at what time it was first learned that a needle touched with magnetite or lodestone, pointed to the Pole. It is true, however, that men were using these compasses before they ascertained that the needle pointed to the magnetic north and not to the true north. It is equally true that the Arabs, the Etruscans, the Greeks, the Vikings, and the Italians, as well as the Chinese, were aware of the pole-pointing property of the magnetic needle long before it was applied to nautical purposes.

From whatever source the first compass came, its use on shipboard appears to have been in the crude form of a magnetic needle "six yaches long, or longer, on a pinne" that was thrust crosswise through a straw or a splinter of wood, and floated on the surface of water in a bowl. Such a compass is mentioned in the work of the Augustinian abbot Alexander Neckham of St. Albans (*circa* 1180) who further says that it was used by mariners who were unable to see the Pole Star by reason of obscurity. This is probably the first reference we have to the mariner's compass in any language. There are several more references to the "water compass" before the first pivoted compass is recorded.

This occurs in the *Epistola de Magnete* of Pierre de Maricourt, commonly called Petrus Peregrinus, written in 1269.[3] His account is not only the first description of a pivoted compass but also of the surrounding graduated circle with 360 degrees, and an external rule or alidade for taking sights. From this device the mariner's compass as we know it today was gradually evolved.

[3] A translation of this rare letter will be found in the Elihu Thomson Collection in the library of The Franklin Institute. The part relating to the pivoted compass is on p. 28 of this translation.

Refinements came from many quarters. The pivoting of the compass card so that it turned with the needle (called a "fly") is mentioned by the Italian writer de Buti as in operation in 1380. He says that sailors use a compass "at the middle of which is pivoted a wheel of light paper to turn on its pivot, on which wheel the needle is fixed and the star (windrose) painted." Only one symbol used on these earlier compasses remains in use today, that is the conventional *fleur de lys* used to mark the north point. This design developed from the windrose which was used on old maps and charts before the compass card had come into general use. The eight points of the compass were represented by the eight principal winds of the Mediterranean—Tramontano, Greco, Levante, Scirocco, Ostro, Ponente, and Maestro—as delineated in the Temple of the Winds in Athens. The north point was represented by a spear or arrow head combined with the letter T, for Tramontano, and it was from this combination that the *fleur de lys* evolved about the year 1492. The east point was generally marked by a cross instead of the L for Levante at about the same time, and will be found on old English compasses down to the year 1700.

The eight compass points were expanded to thirty-two. Chaucer, writing in his treatise on the Astrolabe in 1391, says: "ship men rikne thilke partiez in xxxii."

With this compass to guide them mariners could now abandon their costal sailing, and the triumph of oceanic exploration may well be claimed for this invaluable instrument, for without the confidence inspired by its guidance Vasco de Gama, Columbus, and Magellan would hardly have dared venture so far into unknown waters. The voyage of Columbus was to re-act upon our knowledge of terrestrial magnetism in leading to the discovery of magnetic variation.

The card was fixed and placed at the bottom of the box below the needle by compass makers of Nuremberg and Bruges toward the end of the sixteenth century, and very shortly afterwards the gimbals, or suspension ring for counter-acting the rolling and pitching of the ship, were introduced. Thereafter improvements came slowly, although there are frequent mentions in nautical literature of the unsatisfactory performance of the compasses in use. By the year 1750 the needles of merchant ship's compasses were made of two pieces of steel bent in the middle and united in the shape of a rhomb, or spinning top. Godwin Knight of Oxford substituted straight steel bars of small breadth, hardened throughout and suspended edgewise. He demonstrated that this Chinese method of suspension conduced to sensitivity. Knight long kept his invention secret, and another man received public credit for the idea in 1751 when the Royal Society awarded the Copley Medal to Canton for this very invention.

After Knight's death compass makers either lost the art of making good needles or they became uncommonly careless for, in 1820, an

English mathematician called Peter Barlow informed the Admiralty that "half the compasses in the British navy were mere lumber and ought to be destroyed." He offered suggestions for compensating compass errors by introducing discs of soft iron to correct the ship's own magnetic effect, for iron was becoming more generally used in construction. His work was substantially the only major contribution to the improvement of the mariner's compass until the genius of Lord Kelvin was accidentally directed to the subject, and he produced a greatly improved instrument.

The compasses in use were sluggish in action and would sometimes stick entirely. Their construction was ill adapted to naval use because the concussion of gun-fire would throw them out of service. When a vessel rolled in stormy weather, the needle was inclined to oscillate so much that it made readings difficult. Some of these defects arose from the weight of the moving part, which Kelvin proposed to reduce.

He made a thorough investigation of the whole subject of the mariner's compass, and was able to advance suggestions for the remedy of most errors. To overcome the greatest defect, the permanent magnetism of the ship itself, he placed permanent magnets beneath the compass bowl, and to correct for any temporary induced magnetism of the ship's hull, he placed two globes of soft iron, one on each side and on a level with the compass card. Instead of a single needle, eight small needles of thin wire were fixed like the rungs of a ladder on two parallel silk threads and slung from an aluminum ring. The frictional error of this light moving part was thereby reduced to $\frac{1}{4}$ degree.

The Kelvin compass is now known as the "dry" compass because it was found to be useful enough on merchant ships but had limitations under battle conditions. It was superseded on naval vessels by the "liquid" compass. In the latter, the compass floats on a liquid (water mixed with alcohol to prevent freezing), and bears only slightly on the pivot.

As the magnetic compass needle points to a pole which is several hundred miles from the geographic pole, all readings on its card are subject to variations that differ widely at various points on the earth's surface. Then, additional compensation must be made for deviation due to magnetism hammered into the vessel during building and by magnetism induced in the soft iron of the ship's construction by the earth's magnetic field. Variation and deviation could become grave hindrances to safe navigation unless constantly observed and adjustments made.

About 1910, Elmer Ambrose Sperry applied the principle of the earth's rotation to a new device which he called the "gyro" compass. This is operated by a spinning gyroscope and is quite independent of the earth's magnetism or the magnetic attraction in the iron and steel of the ship's structure. Moreover, the needle points unswervingly to the

true north, so that corrections need be made for neither variation nor deviation.

The master gyro compass is located below decks. It has four essential features: the gyroscopic system or sensitive element, the phantom ring in which the former is supported, the mercury ballistic to overcome the effect of rolling, and the spider, in which the phantom ring is supported.

The gyroscope is a heavy wheel rotated by electric current at a speed of 6000 revolutions per minute. This form of compass relies upon two properties of this spinning wheel: (1) gyroscopic inertia which is shown by a considerable resistance opposed by the gyroscope to any couple tending to turn its spinning axle into a new direction, and (2) precession, which is the name given to the movement of the axle which occurs when such a couple is applied. The phantom ring is so connected that it must follow all the movements of the sensitive element about the vertical axis. The compass card is mounted on the top of the phantom ring. The mercury ballistic is a system by which mercury flows from one cup to another to make compensation for the ship's rolling. It is the equivalent of an ordinary pendulum, but working in the opposite direction. The spider element supports the phantom ring and serves to drive it to follow all movements of the sensitive element about its vertical axis. It also carries a transmitter which conveys the compass bearings to "repeater" instruments situated at various parts of the ship where bearings require to be known.

A course recorder is operated electrically by the master compass. This is a printed chart on which is recorded all changes of the ship's course and the times they take place. These course recorders are valuable permanent records. At the conclusion of a voyage they are usually detached and entered as part of the ship's log. They are admitted in court as legal evidence. In cases involving collision it is frequently impossible for the ship's officers to remember accurately the sequence of changes of course leading up to the collision. The course recorder does this very accurately, often marking the point of impact with an indication when the pen was roughly jogged.

The latest development of these devices permits the vessel's course to be laid upon a chosen bearing, and the ship's head is held automatically to that bearing by the gyro-mechanism, familiarly known as "Metal Mike." This form of automatic control is not used, of course, in narrow, busy, or winding channels, where frequent adjustments of the helm are required. It is reserved for use only when the ship's course remains constant over a long distance. On these occasions it serves a very useful purpose, for steering a ship by compass is a monotonous task and the best of human helmsmen will allow the ship's head to wander after the lapse of some time. The minimum use of the helm means a maximum use of the ship's propulsive power which the engines

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are delivering. Human frailty and fatigue being what they are, it became wise to turn over control when possible to a mechanism which would instantly detect any deviation from the course, and apply the necessary adjustment to the rudder to correct it. This is done by the gyro-pilot.

THE PELORUS

In order to secure a wider field of vision around the horizon when smokestacks, masts, and ventilators interfere with the view from the

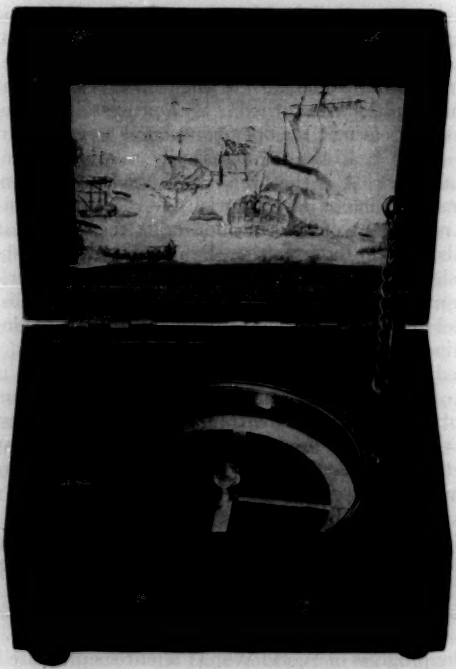


FIG. 1. Small pelorus, with colored print of Dutch men-of-war in lid.

standard compass, auxiliary means of taking bearings must be provided on the wings of the bridge. These take the form of gyro-repeaters if the ship is fitted with a gyro-compass; or a pelorus, if the ship carries only a magnetic compass. A pelorus is a dummy compass card without magnets. The card can be rotated by hand until any desired degree or point of the card is in line with the lubber's line, which is set to coincide

with the ship's keel. Sighting vanes are then used to take a bearing exactly as they would be on the standard magnetic compass. However, the dummy card must be set to read the true, magnetic, or compass course, and the necessary adjustments made in calculation.

RADIO BEARINGS

Although in no way connected with the use of the compass, the modern method of locating a position at sea by radio direction finding cannot be omitted. Government radio beacon stations located on important lighthouses and lightships transmit identifying signals which are picked up by means of an especially designed antenna carried by the ships. The operator turns this antenna until the signal he is receiving reaches its maximum volume. He then observes the angle through which the antenna has been turned. By a process of triangulation from two or more such bearings, the operator secures a very accurate location of the ship. Such bearings are necessarily relative bearings, and not magnetic bearings, that is they refer to the ship's head unless a gyro-repeater is installed in conjunction with the radio direction finder.

Another refinement of location finding is the sonic system of submarine signals transmitted from these lighthouses and lightships. These underwater signals travel with greater certainty from interference than do radio signals, which are subject to atmospheric distortion. A cruising vessel furnished with one of the underwater receiving apparatus may determine the bearing of the transmitting station. When the vessel is fitted with both radio and underwater receiving apparatus it is possible to determine distance with considerable accuracy as the radio and submarine signals are transmitted simultaneously, and the difference in the times required for the signals to travel through the two media is the basis for calculating the distance travelled. Sound travels through water at the speed of 4800 feet per second, while the rate for radio signals is practically instantaneous.

For aerial navigation, radio beacons are placed at convenient spots, such as airfields, and send out continuous signals forming a "beam" along which the pilot conducts his airplane.

Radar

During the progress of World War II scientists presented navigators with two aids employing principles which were entirely new, and which removed navigation from all dependence upon optical systems. The first of these was radar, used in nearly all phases of combat operations.

A radar set on a ship provides the captain and pilot with complete information about the objects around the ship. It will show distance and position of other vessels, buoys, islands, or land masses so that a safe course can be steered. The radar set is entirely self-contained, furnishing information to the operator without contacts with other

ships or shore bases. This feature is of importance under weather conditions that render radio communication difficult or impossible. Equally important is the fact that radar furnishes its information instantaneously.

In a matter of a few seconds a radar set is able to produce a map-like display of the objects around it. This display is produced on a screen resembling those used in television sets. If the radar set is on a ship in motion the display changes continuously as the vessel moves, and moving objects within range are seen to move on the viewing screen.

A radar set includes a special radio-type transmitter, an antenna, a receiver, and a viewing screen or indicator. Objects are detected by the transmitter sending out a pulse, or short spurt, of radio waves. The transmitter produces the energy which is sent out from the antenna in a narrow beam. The antenna is rotated so that the beam sweeps the area within range. Objects which lie within the path of the beam reflect back to the receiver a portion of the energy transmitted. The receiver is tuned to pick up the reflected energy, just as a radio receiver picks up the direct signals from a broadcasting station. The radar receiver passes the reflected signals through special electronic circuits to the visual viewing screen where they form the map-like picture which may be "read" by the operator.

Human vision is assisted by telescopes in daytime and searchlights at night but fog can render these instruments relatively useless. Radar sets, employing short radio waves, will penetrate the fog and will be reflected.

Although the radar viewing screen does not present a picture with the same clarity, it may be likened to a motion picture. Island and coast-lines are represented with close approximations to their true forms, while smaller objects, such as ships and buoys, are shown as specks. Since all such objects, whether moving or stationary, must be avoided by the navigator, their appearance on the screen as a speck of indefinite outline is sufficient warning to ensure caution.

Loran

While radar was quickly adopted as an invaluable aid to navigators it was restricted as to range. The principle of using radio signals was modified and combined with time measuring techniques to produce Loran, the long range navigation device. In the employment of Loran, two ground stations transmit a series of pulses in such a manner that the pulses of one are distinguishable from those of the other. The interval from the emission of a pulse from one station to the emission of a pulse from the other has a fixed, known value. The interval between these pulses as they are received by the navigator depends on his location. It will be equal to the fixed value if the vessel is equally distant from both transmitting stations. It will be greater than the

fixed value if he is nearer to station A, for then the pulse from station B, having farther to travel than the pulse from station A, will fall behind it in time. It will be less than the fixed value if the ship is nearer to station B, for then the pulse gains by its shorter journey. Every distinguished interval characterizes a different hyperbola of position, which is a fixed line on the earth's surface and may be computed and drawn on a chart.

Two pairs of stations (which may be three stations grouped in different pairs) define two intersecting lines of position, forming a Loran grid. Two observed time intervals, one from each pair of stations, define an intersection or point. The navigator is furnished with a receiver having a cathode-ray tube, on the face of which are displayed the successive incoming pulses. The time intervals are accurately read on numbered dials. The navigator enters the chart with the numbers as read, and finds by inspection the corresponding point among the grid lines of the system. Fixes of position may be obtained at distances of 1400 nautical miles by using reflections of the signals from the lower ionosphere.

QUADRANTS, SEXTANTS, ETC.

For their short coastal voyages, the ancient mariners found little need for instruments to aid their navigation, but when trade between the South and North of Europe through the Strait of Gibraltar began to develop, navigators experienced the need of a reliable means of locating their position at sea. The simple need became a matter of pressing urgency when the great voyagers, turning the prows of their ships into the south, lost sight of their one constant guide, the Pole Star.

The use of astronomical instruments of observation for position finding at sea is predicated upon the existence of tables which show the declination (distance north or south) of the sun from the equinoctial (celestial equator), and of star positions. Latitude was ascertained by measuring the sun's angle of altitude at its meridian height, plus or minus the angle of declination for the day of observation. Tables of the sun's declination had been compiled before the time of the Ptolemies, but it is difficult to say when they were introduced for nautical purposes. Manuscript copies of these tables were to be found in the observatories and other places of learning, but it is improbable that many ship captains possessed them before the time of the great voyages.

The first tables to appear in print were restricted in scope to a period of one or two years. The most comprehensive set was published in 1496 by Abraham Zacuto in his *Almanach Perpetuum*. This work was known to Columbus in his later voyages. But not until 1509 was there a set of tables which could be called satisfactory to the unlettered shipmaster. This came with the publication in Portuguese of the *Regimento do Estrolabio*. From this time onward there was less difficulty about the determination of latitude from the sun's declination.

Other tables of star positions quickly followed to meet the needs of those who were compelled to rely upon astronomical observations to find their positions at sea.

The *astrolabe* was the first mechanical device used for measuring angles. It had been in use for many years (it was known to Hipparchus in 150 B.C.) but in the service of astronomers it had acquired a degree

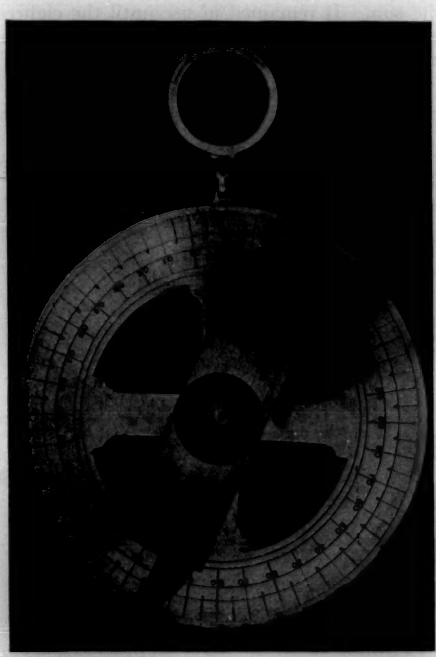


FIG. 2. The astrolabe, assumed to have been invented by Hipparchus in Greece in about 150 B.C. and used by Persians, Arabians and Moors during the Middle Ages and later by Europeans.

of complexity which rendered it unsuitable for the less scientifically minded mariner. By the year 1300, however, a simplified form had been devised which came into maritime use.

In this simple form, the astrolabe consisted of a graduated circular disc, six to eight inches in diameter, with a revolving sight bar pivoted at the center of the circle. The observer held the instrument on his

thumb freely suspended from a ring, and directed the sight bar to the celestial body whose angle he wished to measure. The angle between the angle of the sight bar and the horizontal base line on the astrolabe was then read on a graduated scale.

The astrolabe was never an accurate instrument in the hands of a seaman on the swaying deck of a ship, and it is not improbable that its principal function was to check the hour by determining the mid-day position of the sun. It remained in use until the eighteenth century, and was held in esteem by Italian seamen long after it had been abandoned by other sailors.

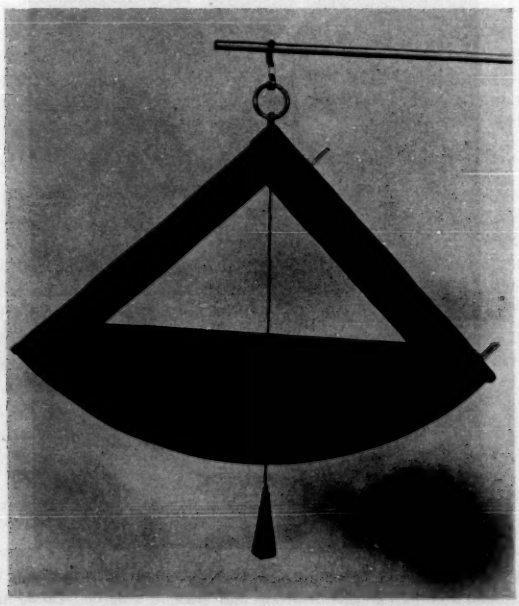


FIG. 3. The quadrant, used at the time of Christopher Columbus.

The *quadrant* had also been in use on land before it was adapted to nautical use. From an entry in Columbus' log we learn that his quadrant was a clumsy affair, only an arc and a plumb line. The arc was a graduated quarter circle and the ends were joined by two wooden bars forming a right angle. A weighted cord was suspended from the vertex of the angle so that it fell across the graduated scale of the arc. Peep

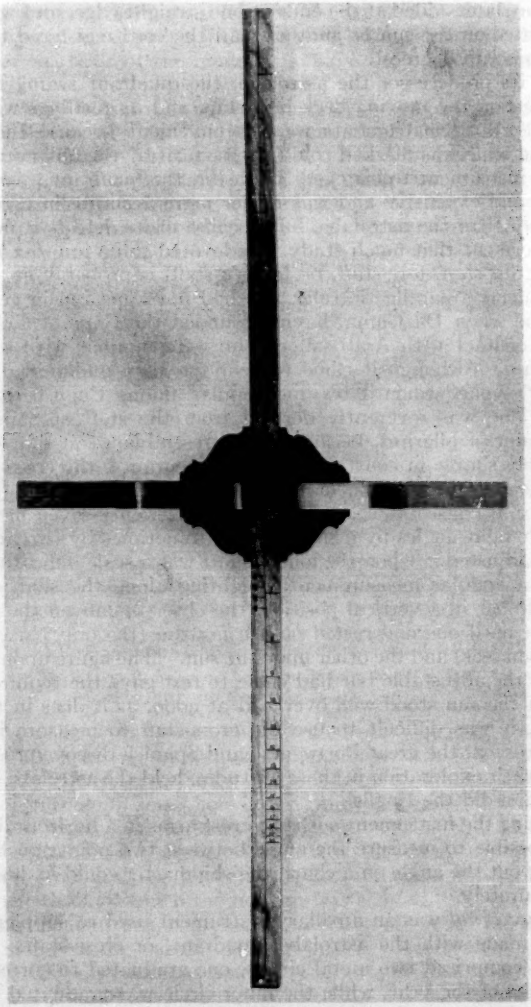


FIG. 4. The cross staff, used in the 16th and 17th centuries. The observer had to look directly at the sun.

sights were later added at the ends of one straight edge, and when these were sighted on the sun or another star, the cord registered the height of the object in degrees.

Like its predecessor the astrolabe, the quadrant swung too freely when used on the moving deck of a ship, and its readings were rarely accurate. Both instruments were inconvenient because the face on which the scale was marked could not be read by the observer while he held the instrument to his eye. However, the quadrant was less cumbersome and expensive and was rather more accurate in a rough and ready way than the astrolabe, but because of its defects it need cause no wonderment that much study was devoted to its improvement.

The *cross-staff*, fore-staff, or Jacob's staff, is probably an evolution from Ptolemy's parallactic ruler. It had not appeared in general use in Europe when Da Gama, having rounded the Cape of Good Hope, came in contact with Arab sailors who were familiar with some such instrument. Although it came to bear the very undignified name of "the hog's yoke" when it became popular among English seamen, its proper name was reverently derived from the staff of Saint James, patron saint of pilgrims, because of the resemblance in shape. While deceptively simple in construction and appearance, the cross-staff was not less learned in its mathematics than was the astrolabe.

Briefly, it consisted of a light staff about twenty-seven inches long, crossed at right angles by a shorter arm (sometimes by two arms) that could be adjusted. Upon the longer shaft was a scale indicating ninety degrees of angular measurement. Sighting along the shaft with the adjustable bar in a vertical position, the observer moved the bar back and forth until one end rested on the horizon (the only "fixed" point on the open seas) and the other upon the sun. The figure upon the scale at which the adjustable bar had come to rest gave the required angle.

When the sun stood well overhead at noon, as it does in the lower latitudes, it was difficult to use the cross-staff to measure its angle. For this reason, the great Portuguese and Spanish discoverers, who did much of their exploration in these latitudes, held the astrolabe in higher esteem than did the English.

By using the instrument with the cross arms in a horizontal position it was possible to measure the angle between two points on land, and by laying out the angle on a chart, the shipmaster could fix his position quite accurately.

The *nocturnal* was an auxiliary instrument used to supplement the readings made with the astrolabe, quadrant, or cross-staff. This instrument comprised two metal circles, one graduated to correspond to the months of the year, while the inner circle was graduated to correspond to the twenty-four hours. Observations were made by setting the circles to the correct date, and peering at the Pole Star through a hole at the common center of the two circles while moving a long arm,

pivoted at the peep-hole, until its free end pointed to the two stars in the Little Bear farthest from the Pole Star. The reading made by this bar against the scale of the inner circle gave the approximate hour of the night.

The *backstaff* was a vast improvement over any of its predecessors. It was developed by Captain John Davis, a celebrated English navigator, from an earlier instrument he had devised in the year 1594. In all previous instruments the observer had been compelled to look in two directions at the same time when making a reading. Moreover, he had been forced to look directly at the sun, and was thus blinded by its glare unless it was hidden by a cloud.

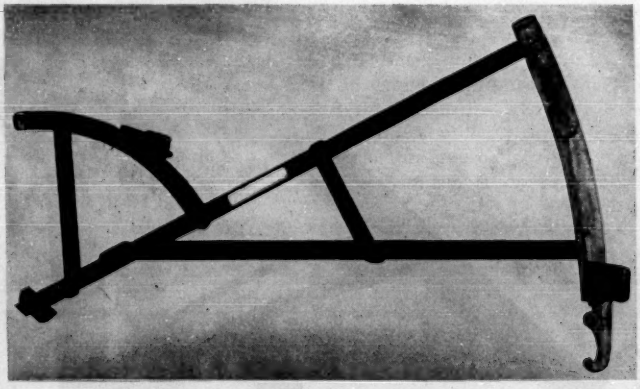


FIG. 5. The backstaff, improved by Captain John Davis in 1590 and which can be used with the sun behind the observer.

Davis' backstaff was a quadrant divided into two arcs, one of sixty degrees of about six inches radius, and the other thirty degrees of two feet radius. The observer stood with his back to the sun and sighted the horizon through a small hole in the thirty-degree arc and a slit in a vane at the other end of the instrument. When the horizon was correctly sighted, the observer moved a shade vane working on the sixty-degree arc, until he brought the sun's shadow into coincidence with the slit through which the horizon was sighted.

The instrument was constructed entirely of wood, including the sighting and shadow vanes. It acquired a considerable popularity under a variety of names, as double quadrant, English quadrant, etc., and was the favored instrument of American navigators well through the eighteenth century.

Meanwhile, several refinements which were to add greatly to the perfection of the sextant when it arrived, had come into use. The

Vernier scale had been introduced for greater accuracy in readings; Gascoigne had applied the telescope to the quadrant; and Hevelius had invented the tangent screw to provide slow and steadier adjustment.

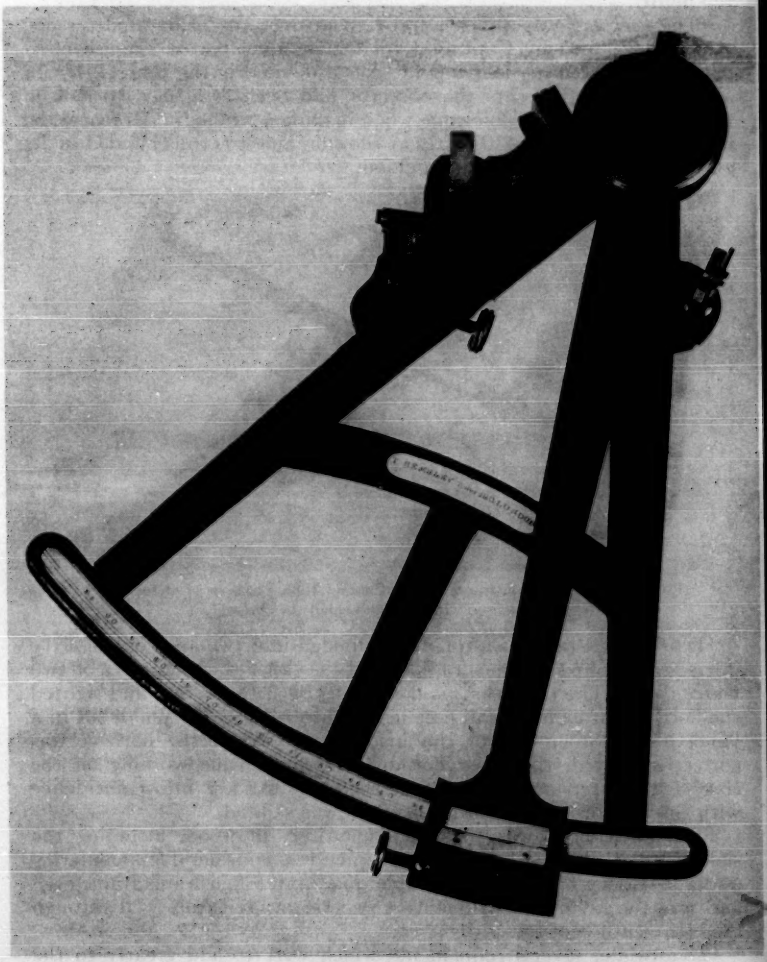


FIG. 6. The improved quadrant, a late 18th century instrument made by Thomas Helmsley, London.

The *sextant* may be said to have had its origin in a suggestion offered by Robert Hooke, the Oxford scientist, in 1666. He suggested that by using a reflecting mirror in the quadrant it would be possible for the observer to see the two objects between which the angular distance had to be measured, and to see one superimposed upon the other. Shortly afterwards, Newton recognized the value of such an instrument for navigation. He designed one, but no sextant made by or for him has come to light.

The modern reflecting sextant was invented independently in America and England. Thomas Godfrey of Philadelphia (in whose house Benjamin Franklin lived for some time) was a glazier by trade but a mathematician of no mean caliber. He constructed a sextant in 1730 which was used by Joshua Fisher in his survey of the Delaware Bay, and later by George Stewart, mate of the sloop *Truman* (George Cox master) on voyages to Jamaica and Newfoundland. This sextant (an improvement of an earlier one of uncertain date) was described in a letter by James Logan which was not published until 1734.[4] The Royal Society had received a similar instrument from an English country gentleman named Hadley, who had been working independently upon the instrument. Being unable to determine which of the two contestants for the honor of priority was entitled to it, the Society awarded both a prize equivalent to $1000. In Godfrey's case this took the form of household furniture, since the Society had evidently been informed that he had a weakness for alcoholic liquors.

In spite of the simultaneous invention, the sextant became universally known as Hadley's sextant. Actually, it was an octant, that is to say, its arc covered 45 degrees. Hadley's principal superiority over Godfrey's instrument lay in the use of a telescope along the observing radius. The sextant is held vertically in the hand to measure the altitude of an object, or horizontally in the plane passing through two objects to measure angular distance. The objective glass was only half silvered so that the observer could sight directly upon one object while bringing the reflected image of the other into coincidence.

Originally sextants and octants were constructed of wood, the arms being from 19 to 22 inches in length, as compared to the modern instrument's 6 or 8 inches. Brass and ivory fittings were added for their embellishment, as were shade glasses, Vernier scales, etc. The wooden construction proved to be unsatisfactory, for in damp climates the material would warp and bend. To overcome this defect, the metal construction was introduced in the middle of the nineteenth century. These were larger still than the modern sextant. Reduction in size was effected during that century, when sextants of brass and bronze frames with silver arcs became uniform. They were true sextants of 60 degrees, with the arc divided into 120 graduations. The index arm

[4] *Philosophical Transactions of the Royal Society*, Vol. vii, p. 672.

had a Vernier scale furnished with a magnifying glass for fine reading. The better instruments are fitted with other refinements to meet varying needs and conditions.

As it is now made, the sextant combines the greatest simplicity with the greatest precision. It is probably the most perfect appliance for hand manipulation that has been invented. No one who has not held a sextant in his hand and seen how local time can be determined to a second, or the latitude can be fixed to within a few hundred yards, can realize the beauty of this instrument, nor the sense of power it gives to the user.

Difficulties have arisen in taking altitudes of celestial bodies when the horizon was invisible or indistinct, as in hazy weather, so that a new instrument was developed which provides an artificial horizon mark. This instrument is called a *bubble sextant* to distinguish it from the conventional instrument. A floating bubble serves the purpose of the horizon and, in taking a sight, the instrument is adjusted until the reflection of the celestial body is brought to rest in the center of the bubble. The bubble is difficult to control owing to the motion of the ship or airplane so that the error in a measured altitude of a celestial body is prone to be greater than when the visible horizon is used.

Since the sextant is an instrument for measuring angles, mention might be made here of the *stadimeter*, which is another instrument used for measuring small angles to calculate distances. Its principal use is to enable a vessel moving in formation to maintain its allotted position.

Neither the great navigators of the Age of Discovery nor any others for two more centuries had the means of determining their longitudinal position with any degree of accuracy. The best they could do was to keep a record of their compass course and to make an estimate of the distance covered on each bearing. When these were computed and transferred to the chart, the navigator could calculate his position east or west of the point of departure. This method was called "dead reckoning," and it will be realized that it was no easy matter to calculate absolute distance when the vessel had to tack frequently in contrary winds, or was buffetted by storms. One early writer speaks of longitude as determined by the mariner of his day as the "imaginative position," and this was probably more nearly true than the writer suspected.

The instruments available before the eighteenth century were incapable of rendering accurate results. When Champlain wrote his treatise on navigation in 1632, he expressed the pious conviction that the good Lord did not intend that man should so penetrate the mysteries of creation as to be able to determine longitude at sea. Philip of Spain adopted a more optimistic attitude (at least as regards navigation), for he offered a rich reward to the man who discovered the means of determining longitude. Later, the British Parliament offered a still higher reward, and the search for the missing link in navigation was diligently pursued.

The method of dead reckoning with inadequate instruments not infrequently resulted in shipwreck. In at least one instance the course of empire was affected by an error "in the logg" of 45 minutes. Eight British ships of war were wrecked in the mouth of the St. Lawrence in the year 1711, when a joint expedition from New England and the parent country was frustrated through the loss of ships and men due to faulty navigation. Another paralyzing loss occurred when dead reckoning showed an open sea ahead of Sir Cloudesley Shovel's squadron when, in reality, they were close in to the shores of the Scilly Isles, where they were wrecked.

The Log

In order that the distance travelled might be calculated the navigator had to have some apparatus for measuring time and speed. It was the inadequacy of the equipment which handicapped the earlier navigators. A rough and ready method of calculating speed employed some 300 years ago was to walk aft, keeping pace with bubbles or some floating object close alongside, chanting a certain ditty as one walked. When the words of the ditty were ended the distance walked along the deck was measured and a unit of measure was thus obtained. More accurate means were available at the time had they been developed. Writing shortly before the Christian era, Vitruvius describes a device then in use on boats propelled by oars. This employed a rotating wheel. Succeeding this, we find no mention of floating "logs" for several centuries. None of the great navigators appears to have used one except Magellan. He appears to have employed some form of apparatus when he sailed from Spain in 1520, but he makes no mention of its operation. Vespucci also mentions the determination of longitude by instruments but gives no clue to the nature of those employed.

The word "log" bears a literal relationship to the nature of the apparatus first used by seamen, for the wooden object they threw overboard was intended to behave precisely like a log of wood. It was intended to float without perceptible progress on the surface of the water, remaining in one place like a marker, while a measured line was paid out from the ship. Newer mechanical logs do not serve as markers; they move with the ship.

Toward the sixteenth century, a practical device was introduced in England. It is described as a small boat-like construction containing a wheel and apparatus for turning pointers on a dial to register fathoms, leagues, and scores of leagues. This was the forerunner of the Harpoon Log which was discontinued because of the inconvenience of having to draw the log inboard to make a reading. Numerous improvements were made to this device until the familiar common log acquired its shape and method of handling. It comprised four essential parts: the chip (or log-ship), the line, the reel, and the glass. The chip was a wooden quadrant weighted on its arc so that it floated in an upright position.

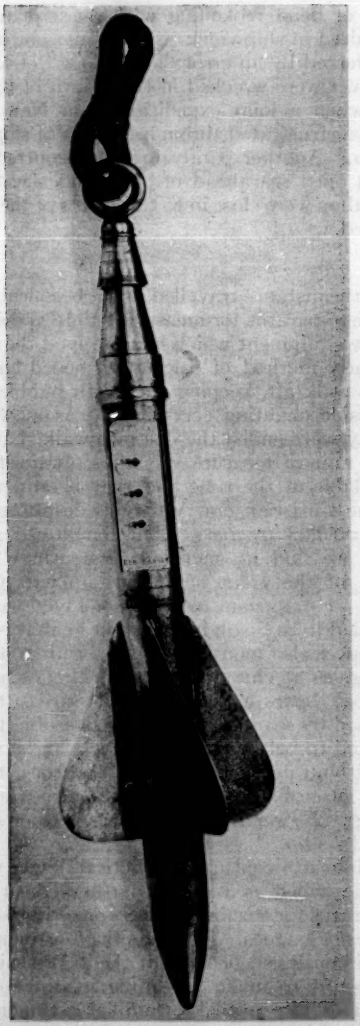


FIG. 7. A harpoon log, Massey's patent device for determining the speed of a ship. The dial is on the rotating part.

It was secured to the line, which might vary in length but which was always marked at known intervals by knots tied in the line. After being well soaked and stretched, it was wound around the reel. When a seaman threw the log over the side, he threw it to windward and paid out the line until a certain point was reached, marked with a red rag. At this stage he called to a companion to "Turn the glass."

This glass was a sand glass. For the purpose of reading the log special sand glasses were designed to run for short durations of time—20, 28, or 30 seconds—according to the space between the knots in the line. They were affected by damp and changes of temperature. Running sand was not ideal as a time measurer, but it had to serve because the mariner had no other.

The distances between the knots in the line had a direct relationship to the duration of the running sand in the glass. For example, a line knotted at every 47 feet 3 inches has the same relationship to a nautical mile of 6080 feet as a 28 seconds glass has to the 3600 seconds in an hour. When the seaman operating the log had paid out five knots of line during the running of the glass, the vessel was said to have travelled five units, that is, it had covered five times the distance of 47 feet 3 inches in 28 seconds, or five nautical miles during the hour.

The speed at which ships travel is still reckoned in "knots" (never knots per hour), a term which combines distance with time, a derivation due to the use of the knotted line in the old logs.

Several types of log are now in use. The Taffrail log (sometimes called the patent or cherub log) consists of a propeller shaped rotor towed at the end of about 150 fathoms of line. The rotor is so adjusted that it makes one complete revolution in a predetermined distance, and the number of revolutions is transmitted through the line to a recorder on the taffrail, which converts the revolutions into distance covered. The great defect of this type of log is its liability to inaccurate rotation when fouled by seaweed or other floating objects. The Nicholson log has a tube which projects from the bottom of the ship into the water. It calculates the speed of the vessel by pressure, which causes the water in the tube to rise proportionately. The Forbes log also uses a projecting tube, but has added a propeller shaped rotor at its projecting end. Both these tube logs have electrical connections by which speed and milage may be read on the bridge.

The Rodmeter used in the United States Navy is an instrument which protrudes through the bottom of the ship's hull into relatively still water. It has a pitot tube with orifice in the leading edge to transmit dynamic pressure, and holes at the bottom and side to transmit static pressure. Both the dynamic water pressure caused by the forward movement of the ship and the static water pressure are conveyed through hydraulic systems to a speed indicator, where a motor-driven centrifugal pump develops a pressure proportional to the dynamic

pressure in the Rodmeter. This can be read on a dial indicator where it has been converted through a series of gears into knots.

The log book used to record a ship's progress from day to day came into early use and, as measurement became more and more accurate, not only were the records more carefully and accurately kept but more uniform detail was entered.

Lunar Reckoning

For somewhat obvious reasons the navigators of the Mediterranean Sea had calculated their longitude only in an eastward direction, using the most westerly known point of land, Ferro in the Canaries, as their starting point. Later geographers adopted St. Michael in the Azores as their zero line because they were under the impression that the meridian of no magnetic variation passed through it. This latter method was in use at the time when mariners pinned their hopes of determining longitude by relating it to variations in the compass needle. Some early American geographers constructed their maps with Philadelphia as their prime meridian with this purpose in view.

Foremost among those striving for better results in the determination of longitude were the English, and they concentrated for many years upon an old idea of using the moon for this purpose. In order to establish the most accurate tables relating to the moon's position, they established the Observatory at Greenwich in 1765, and in their calculations fixed the meridian passing through that place as the prime meridian for all longitudinal measurements.

The principle of determining longitude by the moon is based upon measuring the angular distance between the moon and certain fixed stars as seen at a fixed point on shore (that is, Greenwich). Tables were constructed to give these angles for every day of the year. Local measurements of the angle were made by the mariner who, by comparison with the Greenwich tables, then computed his longitude. It was a slow, complicated, and inexact method but it was so generally adopted that it was hard to dislodge.

The Chronometer

The disasters to which we have alluded, and many others only of lesser gravity, befalling the British navy spurred the Admiralty to offer substantial rewards for a reliable method of determining longitude. The solution of the problem lay in the determination of the exact time, and since time is reckoned by the motion of the earth in relation to celestial bodies, the methods of using the moon were not fundamentally unsound. The mistake lay in the difficulty of predicting the position of the moon from the observations then obtainable. The fact that errors crept into their calculations through aberration and mutation was not unknown to the astronomers and, while they may have been

vaguely conscious of the superior advantages offered by relative comparisions with the altitude of the sun, there was no way by which a check between local time and time at a fixed point could be made.

Local time could always be determined when the sun was not obscured, but the means of having the time at a fixed point accompany the navigator was still unsatisfactory. The practical difficulty of the clocks and watches of the time resided in their incapacity to keep accurate record of the hour because of changes of temperature and the motions of the ship. For some inexplicable reason the discovery of the spiral balance spring by Huyghens in 1675 did not instantly appeal to the time-piece makers. Not until 1735 was a clock submitted to the "Commissioners for the Discovery of Longitude at Sea" as a potential solution to the problem of determining longitude.

The inventor, John Harrison, based his invention on the principle of the gridiron pendulum compensated by two metals of unequal contraction to overcome changes of temperature. Unfortunately for Harrison, the clock was given for test to a confirmed believer in the lunar method of reckoning longitude, and he had to wait for many years before receiving the award which had been promised. By this time he had greatly improved his time-piece by adapting it to a watch through the employment of a "grasshopper" escapement.

Although Harrison is entitled to the credit of being the first to provide a way of carrying fixed time on shipboard for comparison with local time ascertained by solar observation, the modern chronometer is not the direct descendant of his time-piece. Much remained to be done by French and British horologists (one of the latter, Arnold, gave it the name "chronometer"), before a completely satisfactory instrument was produced, suitable for placing in the hands of the mariner and adjusted in price to suit his purse.

The modern chronometer is a marvel of accuracy, its regularity varying only a few seconds in the course of a month.

We know that time is determined by the rotation of the earth, or as navigators say, by the "apparent" revolution of the sun about the earth. Since this apparent revolution of the sun is accomplished in 24 hours, we know that the sun appears to travel over 15 degrees of the earth's surface in one hour (one twenty-fourth of 360 degrees), or one degree in four minutes. Thus, when the sun is directly over the meridian passing through Philadelphia (not necessarily directly overhead) it is twelve o'clock noon, but as the sun will not reach the meridian of Chicago until an hour later (it is approximatley 15 degrees away) it is only eleven o'clock there, and nine o'clock in San Francisco.

With this unvarying rotation of the earth through fifteen degrees every hour, it becomes possible to fix one's location east or west of a given point at which the hour is known. All navigating charts fix this point along the meridian which passes through Greenwich, England,

which is marked zero on the charts. The navigator sets his chronometer by Greenwich Civil Time (or Greenwich Mean Astronomical Time, often called Universal Time, where the hours begin at midnight), so that he always has a constant reference to the zero point on his chart. By measuring the altitude of the sun at any time he can, by reference to his chronometer, find how many hours and minutes he is ahead or behind Greenwich time. By allowing four degrees for every four minutes of difference, he can determine how many degrees he is east or west of the zero line on his chart.

Formerly, three chronometers were carried so that when an irregularity occurred on one it was revealed by the others. Today, when time can be checked by means of radio signals from authorized stations, one or two serve the purpose.

With the chronometer in his possession, the mariner was now fully equipped to ensure accurate navigation. North, south, east or west his course could be laid and followed with an assurance such as never before had been known. For a full thirty centuries we have followed the mariner's progress in navigation: from Solomon's admission of ignorance concerning the navigator's skill up to the time of the modern shipmaster's complete knowledge. One thing only has remained unchanged during this long period of time, and that is the Sea itself. Whether the controlling hand had to steer the sea raider's long ship or the grimy little coaster was driven by a Diesel engine, the sea has remained unchanged in its behavior and still challenges the wit of man. No instrument has ever been invented that can replace the unceasing vigilance with which the mariner must observe its vagaries and caprices.

HIGH-SPEED DIRECT-INKING RECORDING SYSTEM *

BY

MARTIN A. POMERANTZ[1] AND ROBERT C. PFEIFFER[1]

ABSTRACT

A direct-inking recording system which is capable of resolving impulses separated in time by 0.01 sec., and which can operate continuously for long periods of time, has been utilized in telemetering cosmic-ray signals from balloon-borne equipment. A tape-reader mechanism permits rapid analysis of the records. The device has applications in various types of physical experiments, as well as in other fields.

I. INTRODUCTION

The well-known limitations of photographic recording techniques become particularly manifest in applications involving long periods of continuous operation combined with the requirement of a relatively short resolving time. It therefore becomes necessary to resort to devices embodying a direct-inking pen, tape puncher, or other printing arrangement for producing marks on a paper tape. Instruments of this type (1, 2)[2] have been utilized, for example, in the recording of radio signals transmitted from equipment carried aloft by free balloons. The speed with which previous systems could be operated, however, has been limited by the mechanical response time of the pen assembly; consequently only rather low, or scaled-down counting rates could be handled.

A system incorporating a commercially available high-speed magnetic oscillograph has proved extremely satisfactory for continuous recording of signals received from cosmic-ray radiosondes. Comparatively inexpensive, light in weight, and easily transported, the arrangement to be described has been in use for two years in an extensive program of cosmic-ray investigations. It has provided trouble-free performance both in the laboratory and under difficult field conditions.[3] Furthermore, it has operated without interruption during flights remaining aloft as long as 15 hr.

Although designed primarily for telemetering information relating to cosmic-ray intensity measurements (3), this arrangement could easily serve various other purposes, as will become apparent from the description of its characteristics. For example, it might be utilized

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.

[1] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

[2] The boldface numbers in parentheses refer to the references appended to the paper.

[3] During the National Geographic Society-AAF Eclipse Expedition to Bocaiuva, Brazil in May, 1947.

advantageously in conjunction with ionization chambers, proportional counters, high speed counting circuits, or counting-rate meters. In fields other than physics, such as biology or astronomy, the recorder could be readily adapted to kymographic, chronographic, or other similar applications.

II. RECORDING APPARATUS

The present device incorporates the Brush BL201 magnetic oscillograph [4] with certain modifications. The magnetic penmotor (4) reproduces electrical signals in the frequency range from d.c. to 120 cps. Multichannel oscillographs could equally well be modified for this

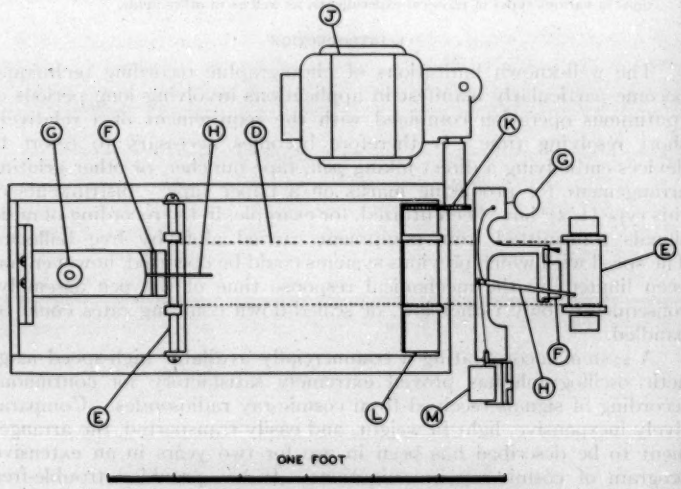


FIG. 1. Diagrammatic sketch of the high-speed direct-inking recording arrangement as viewed from above.

application. In its original manufactured form, however, the instrument is not designed for extended operation at high speeds, and in fact the chart paper capacity is sufficient for runs of a maximum duration of 6 min. This is remedied by the arrangement illustrated in Figs. 1 and 2. Although the paper-drive mechanism and gear-train for selection of speed have been removed for the present purposes, it is convenient to retain the other components.

The paper tape is fed from the large reel *C* which can accommodate 2500 ft. of paper. The outer disc is demountable, being held in position

[4] Brush Development Company, Cleveland, Ohio.

by a knurled threaded retainer. The rolls of paper are supplied with wooden center cores into which a brass bushing is forced. The latter is provided with a pin which fits into a groove along the axle of the reel assembly, thereby preventing slipping of the paper with respect

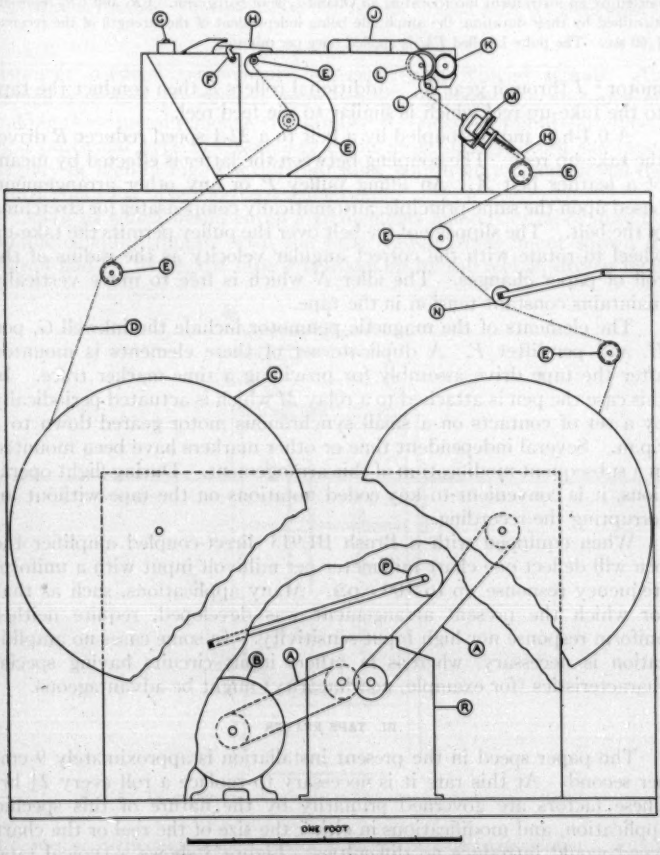


FIG. 2. Diagrammatic sketch of the high-speed direct-inking recording arrangement as viewed from the side.

to the reel. The paper tape D then passes over a roller E and on to the platten via two rods E. The paper drive is accomplished between the two pressure rolls L, the upper of which is powered by a speed-reducing

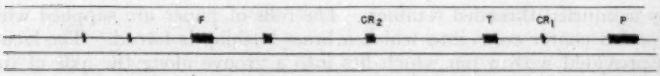


FIG. 3. Typical tape record obtained with the recorder during a free-balloon flight. mitted by an instrument incorporating an Olland-type of barograph. CR_1 and CR_2 represent identified by their duration, the amplitude being independent of the strength of the received 1/60 sec. The pulse labelled *TM* is applied once per minute.

motor [5] *J* through gear *K*. Additional rollers *E* then conduct the tape to the take-up reel which is similar to the feed reel.

A 0.1-h.p. motor coupled by a belt to a 22-1 speed reducer *R* drives the take-up reel. The coupling between the latter is effected by means of a leather belt *A*. An idling pulley *P* or any other arrangement, based upon the same principle, automatically compensates for stretching of the belt. The slippage of the belt over the pulley permits the take-up wheel to rotate with the correct angular velocity as the radius of the roll of paper changes. The idler *N* which is free to move vertically maintains constant tension in the tape.

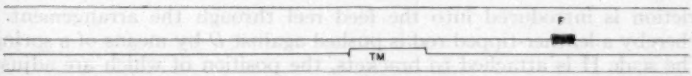
The elements of the magnetic penmotor include the inkwell *G*, pen *H*, and pen-lifter *F*. A duplicate set of these elements is mounted after the tape drive assembly for providing a time-marker trace. In this case the pen is attached to a relay *M* which is actuated periodically by a set of contacts on a small synchronous motor geared down to 1 r.p.m. Several independent time or other markers have been mounted in a subsequent modification of this arrangement. During flight operations, it is convenient to key coded notations on the tape without interrupting the recording.

When equipped with a Brush BL913 direct-coupled amplifier the pen will deflect one chart millimeter per millivolt input with a uniform frequency response up to 100 c.p.s. Many applications, such as that for which the present arrangement was developed, require neither uniform response nor high input sensitivity. In some cases no amplification is necessary, whereas in others input circuits having special characteristics (for example, non-linearity) might be advantageous.

III. TAPE READER

The paper speed in the present installation is approximately 9 cm. per second. At this rate it is necessary to replace a roll every 2⅓ hr. These factors are governed primarily by the nature of this specific application, and modifications in either the size of the reel or the chart speed would introduce no difficulties. Figure 3 shows a typical tape record obtained during a balloon flight incorporating a barograph based upon the Olland principle of radio meteorography (5). In this system it is necessary to measure the time interval represented by the tape

[5] Bodine Electric Company, Chicago, Ill. 1/70 h.p., 23 r.p.m. output.



F and *F* are reference signals, and *T* and *P* temperature and pressure respectively, as trans-
cosmic-ray events which triggered the two independent circuits. The various signals are
radio signal in this case. The separation in time between adjacent peaks in a given signal is

distances between temperature, pressure, and fiducial signals. Although a system (3) devised more recently obviates the necessity of making these measurements, the number or counts per minute produced by a particular type of cosmic-ray event must be read from the tape. As may be seen in Fig. 3, a different pulse length may be employed for identifying each of several types of event.

Analysis which would entail a tremendous amount of labor may be completed quite rapidly with the tape reader arrangement shown in Figs. 4 and 5. Here, the tape *F* is taken up by the reel *D*, driven by a

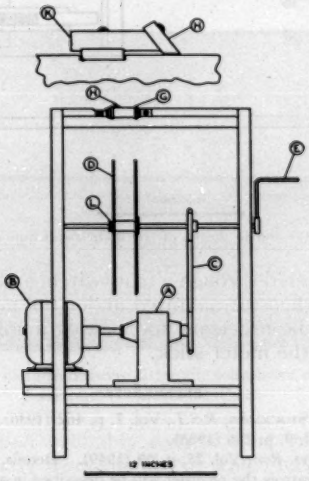


FIG. 4. Diagrammatic sketch of the high-speed tape-reading device.

d-c. motor *B* through a speed reducer *A*. The tape passes over a pulley *G* at either end of the table. The reels can also be turned manually by means of the handles *E*. The roll of tape is loaded by disconnecting the belt *C* and pulling the shaft forward. Construction of the reels is similar to that on the recording unit. To maintain tension in the tape,

friction is introduced into the feed reel through the arrangement *J* whereby a leather-tipped rod is pushed against *D* by means of a spring. The scale H is attached to brackets, the position of which are adjustable. These in turn are fastened to a rod of rectangular cross-section. The latter slides along a way so that the scale can be moved conveniently lengthwise.

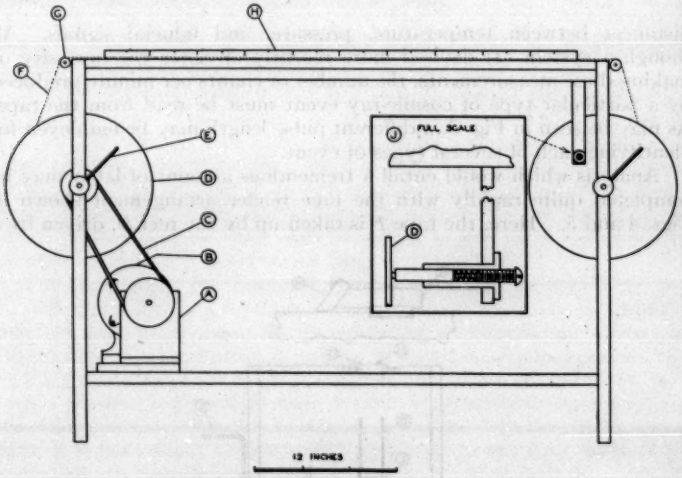


FIG. 5. Diagrammatic sketch of the high-speed tape reading device.

The motor is powered through a foot switch, and the speed controlled by means of a field rheostat mounted under the table. Other types of scale such as would be necessary for making amplitude measurements could easily replace the meter-stick.

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(4) H. B. SHAPER, *Electronics*, Vol. 19, p. 148 (1946).
(5) T. H. JOHNSON AND S. A. KORFF, *R.S.I.*, Vol. 10, p. 83 (1939).

INACTIVATION OF MOLDS BY GERMICIDAL ULTRAVIOLET ENERGY

BY

MATTHEW LUCKIESH,[1] A. H. TAYLOR,[1] THOMAS KNOWLES[1]

AND E. T. LEPPELMEIER[1]

Spoilage of foodstuffs and manufactured products by molds results in great economic losses; therefore, any practical method of reducing these losses is of vital interest. Ultraviolet energy of certain wavelengths has been known to be effective for this purpose, and the advent of more efficient sources of such energy has stimulated interest in obtaining quantitative data regarding its effectiveness. Therefore, the results presented herewith pertaining to the effectiveness of ultraviolet energy in the spectral region of λ2537 are of considerable practical interest and importance.

FIG. 1. Mold cultures demonstrating the prevalence of spores in air sampled at various locations.

Mold contamination probably results most generally from spores which settle out directly from the air, or which have recently been airborne. They have their origins on animal or vegetable matter, much of it outdoors, and may be brought indoors by air currents or on the clothing, shoes, etc. Prevalence of air-borne spores indoors may be shown by exposing open petri dishes with culture media for several hours, then incubating them for several days at room temperature. Figure 1 is reproduced from a photograph of four petri dishes exposed

[1] Lighting Research Laboratory, General Electric Company, Nela Park, Cleveland, Ohio.

in this way in various locations outdoors and indoors. The number of spores collected indoors is greatly increased during and after sweeping the floor, due to stirring up of contaminated dust.

Sterilization by heat is the most common method of preventing mold spoilage, but is not always applicable. It has long been known that ultraviolet energy can also be used as a germicidal agent (1),[2] but its use was not economically feasible before the advent of low-pressure mercury discharge lamps radiating nearly all their ultraviolet energy in the spectral region of λ2537. Fortunately, this is the spectral region of maximal germicidal effectiveness. Following their researches (2) on air-borne micro-organisms, the authors have been investigating the possibilities of mold control by germicidal energy. A condensation of some of the most important findings of our researches, involving several hundred separate tests, is presented in this paper.

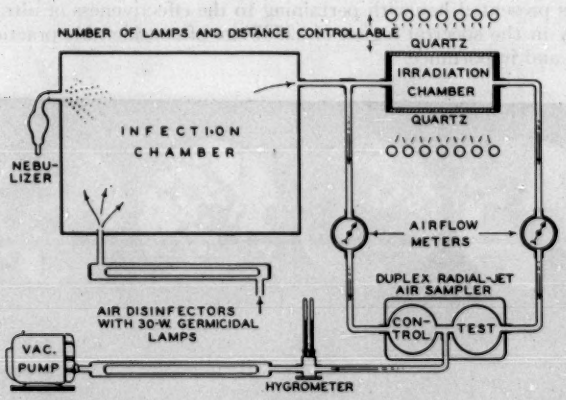

FIG. 2. A simplified diagram of apparatus used in studying the inactivation of air-borne bacteria and fungi by ultraviolet energy of λ2537.

In the period between the time mold spores become air-borne and the time when they produce spoilage, there are at least three periods during which they may be killed by germicidal ultraviolet energy, or at least inactivated so as to be incapable of reproduction. These periods are as follows:

1. When viable spores are air-borne and in motion in the room air. High intensities of suitable ultraviolet energy may be used to inactivate them before they settle onto foodstuffs, etc.

2. When viable spores have settled out of the air onto the floor or

[2] The boldface numbers in parentheses refer to the references appended to this paper.

objects which do not promote growth but from which they may later be stirred up and again become air-borne. Low intensities of ultraviolet energy reflected from walls and ceilings, when upper-air irradiation is used, may accomplish a high degree of inactivation over a period of many hours.

3. When viable spores have become attached to the surface of a medium or material upon which they can grow. Direct irradiation of the stationary spores may be effective in preventing growth, provided too long a period does not intervene between infection and irradiation.

This paper deals with results of our investigations of these three aspects and also with the range of resistivities of various species of molds which are common contaminants.

TABLE I

Dosages (*Et*) of germicidal energy required to inactivate 50% and 95% of various microorganisms irradiated in air and on the surface of culture medium.

E = microwatts of λ2537 energy per sq. cm.
t = exposure time in minutes

	Dosages *Et* to Inactivate			
	Air		Surface	
	50%	95%	50%	95%
Bacteria				
Mixed respiratory (from nebulized saliva)	0.4	3.2	—	—
Mixed respiratory (from sputtered saliva)	2.5*	23.0	—	—
Staphylococcus aureus	0.8	5.2	15.0	80.0
Escherichia coli	2.1	7.4	28.0	110.0
Alpha streptococcus	0.6	3.2	—	—
Beta streptococcus	3.0	11.5	—	—
Yeast				
Torula sphaerica	7.2	50	70	170
Mold Spores				
Mucor mucedo	340	1250	200	390
Penicillium chrysogenum	170	1150	120	320
Scopulariopsis brevicaulis	270	1450	210	490
Cladosporium herbarum	180	1350	120	410
Aspergillus amstelodami	320	1450	250	560
Rhizopus nigricans	250	580	—	—
Aspergillus niger	1800	9000*	1300	3000*

* Estimated value.

In photochemistry and photobiology, the so-called "reciprocity law" is often encountered. If a certain intensity E of radiant energy operating over a certain period of time t produces a given result, it is often found that the same result can be obtained if both of these factors are varied, so long as their product, or dosage, Et is unchanged. The application of this law to the inactivation of bacteria and mold spores

by exposure to germicidal energy has been verified experimentally by the authors for a range of 1000 to 1 in the two factors. The actual intensities of E were 0.5 to 500 microwatts per sq. cm. which cover the ranges encountered in practical installations of germicidal lamps for air disinfection.

In a previous paper (2) the authors discussed apparatus and techniques used in determining the lethal effect of various dosages of ultraviolet on different types of air-borne micro-organisms. A simplified diagram of improved apparatus for this work is shown in Fig. 2. A water suspension of the organism to be studied is nebulized into the infection chamber, from which it is drawn to the duplex radial-jet air sampler (3). By one path air is drawn directly to one unit of the

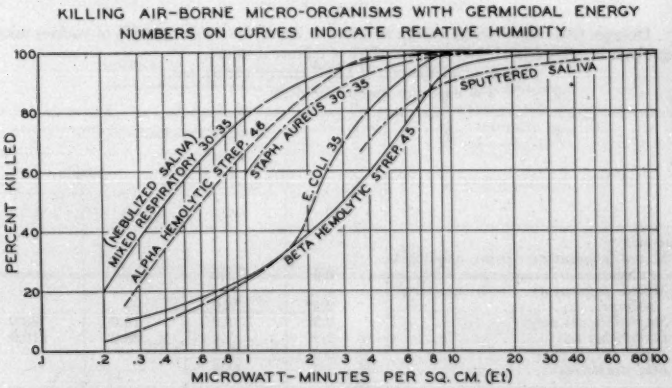
KILLING AIR-BORNE MICRO-ORGANISMS WITH GERMICIDAL ENERGY
NUMBERS ON CURVES INDICATE RELATIVE HUMIDITY
PERCENT KILLED
MICROWATT-MINUTES PER SQ. CM. (Et)
(NEBULIZED SALIVA) MIXED RESPIRATORY 30-35
ALPHA HEMOLYTIC STREP. 48
STAPH. AUREUS 30-35
E. COLI 35
BETA HEMOLYTIC STREP. 45
SPUTTERED SALIVA

FIG. 3. Lethal effect of ultraviolet energy of λ2537 on air-borne micro-organisms as determined by use of apparatus shown in Fig. 2.

sampler, but air sampled by the other unit of the sampler passes through an irradiation chamber. The chamber has quartz windows through which the moving air is irradiated by energy from banks of 8-watt germicidal lamps outside the chamber. The number and distance of lamps and also the air velocity can be varied to obtain a wide range of known dosages. The actual available range of dosage Et was from 0.2 to 2400 microwatt minutes per sq. cm.

Various species of micro-organisms and mold spores were studied with this apparatus in the present and earlier forms. Some of the data obtained are shown in Table I and in Figs. 3 and 4. The lethal curves show a wide range of resistivity of various species of bacteria and fungi. The mixed respiratory organisms, obtained by nebulization of saliva taken from the mouths of human beings or sputtered directly from the

mouth, are very easily destroyed or inactivated while the mixed saprophytic organisms in dust, sampled in movie theaters during cleaning, are about several hundred times more resistant.

The diameter of droplet nuclei from nebulized saliva averages approximately one μ, which is 0.001 mm. or about 0.00004 in. The droplet size from sputtered saliva would probably vary from 7μ to 100μ and larger (4). These relatively large droplets would contain many times more micro-organisms than would be carried by droplet nuclei. The inactivation of micro-organisms by ultraviolet irradiation follows the exponential law (1). This phenomenon probably accounts in part

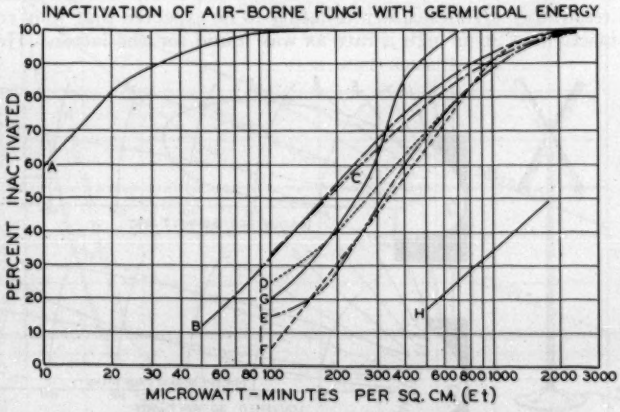

FIG. 4. Inactivation of air-borne fungi (produced by nebulization of water suspension of each) by ultraviolet energy of λ2537.

A. *Torula sphaerica*, relative humidity = 65%
B. *Penicillium chrysogenum* RH = 41%
C. *Cladosporium herbarum* RH = 53%
D. *Scopulariopsis brevicaulis* RH = 79%
E. *Aspergillus amstelodami* RH = 67%
F. *Mucor mucedo* RH = 63%
G. *Rhisopus nigricans* RH = 62%
H. *Aspergillus niger* RH = 55%

for the greater apparent resistivity of the micro-organisms in sputtered saliva as compared with those from nebulized saliva as shown in Fig. 3. The authors have found, in schools and movie theaters, that an over-all reduction of 50 per cent of the air-borne micro-organisms can be obtained with practical installations of germicidal lamps. Since the respiratory organisms are much lower in resistance, it is logical to assume that they would be reduced by a much larger percentage, probably as great as 95 per cent.

The authors have found that *Escherichia coli* and the mixed organisms in saliva increase in resistance to germicidal energy with in-

creasing humidity. However, mixed air-borne organisms sampled in a poultry house appeared to be less resistant at high humidities. These results may indicate that air-borne bacteria are most resistant under humidity conditions most nearly approaching those of their natural habitats. The resistance of air-borne mold spores appears to be relatively unaffected by wide variations in atmospheric humidity.

In a previous paper (2) the authors showed that a very high concentration of air-borne mixed respiratory organisms (nebulized saliva) in a closed room could be rapidly reduced by upper-air irradiation by a single 30-watt germicidal lamp in a suitable reflector or fixture. Since the mold spores are much more resistant to ultraviolet energy than are the respiratory organisms, it was hardly to be expected that they could be inactivated at as high a rate as was found for the latter. Hence

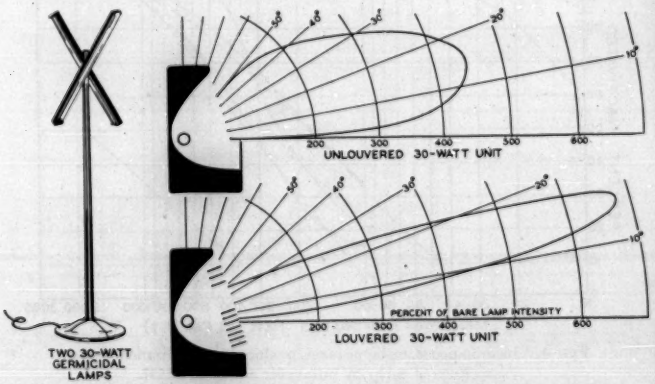

FIG. 5. Three types of germicidal lamp units used to study the inactivation of air-borne mold spores in an experimental room.

for mold-spore reduction it has been customary to recommend direct high-intensity irradiation by germicidal lamps during periods of non-occupancy of the rooms (5).

Intensive studies have been carried out by the authors to determine the lethal effectiveness of germicidal energy on air-borne mold spores in a closed room $17\frac{1}{2} \times 15\frac{1}{4}$ ft., with ceiling $11\frac{1}{2}$ ft. high. As a test organism *Penicillium chrysogenum* was chosen because it is a common contaminant mold of foodstuffs and appears to be fairly representative as regards resistance to ultraviolet energy, when the spores are air-borne. Three systems of irradiation were used, the types of units being as illustrated in Fig. 5. The two bare 30-watt germicidal lamps were used at the middle of the room mounted with their centers 4 ft. above the floor. In another installation the reflector fixtures were mounted so

that the germicidal lamp was about 7 ft. above the floor and irradiated the stratum of air above that level.

From an adjacent room rubber hoses attached to an air pump were carried to two DeVilbiss No. 40 nebulizers in the test room. A water suspension of the spores was nebulized for about an hour before air-sampling began. Usually the air in the test room was stirred by electric fans during the nebulization period, to make the concentration of spores as uniform as possible. The fans were then stopped. Before irradiation with ultraviolet energy, several samplings of the air were made by

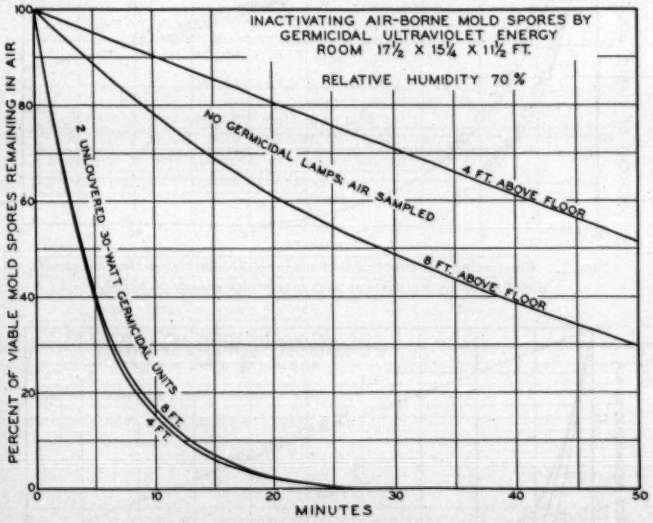

FIG. 6. The normal disappearance rate of *Penicillium chrysogenum* spores that were atomized into the air of a closed room is shown in comparison with the disappearance rate when the air was irradiated with ultraviolet energy.

means of rubber hoses whose intakes were located at the center of the room, 4 and 8 ft. above the floor. These hoses were attached to the two sampling units of a radial-jet air-sampler (3) located in the adjacent room. The germicidal lamp or lamps were then turned on and the air was sampled at various intervals to determine the rate of disappearance of the spores. The rate of disappearance was also determined *without* irradiation with ultraviolet energy from the germicidal lamps.

Many separate tests were made during winter months and typical results of several are illustrated in the charts of Figs. 6, 7, and 8. In

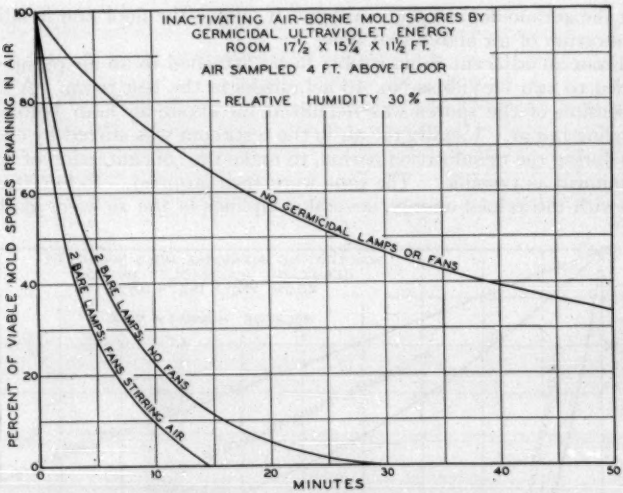

FIG. 7. Illustrating the effect of increased air circulation on the rate of air disinfection by irradiation with ultraviolet energy of λ2537.

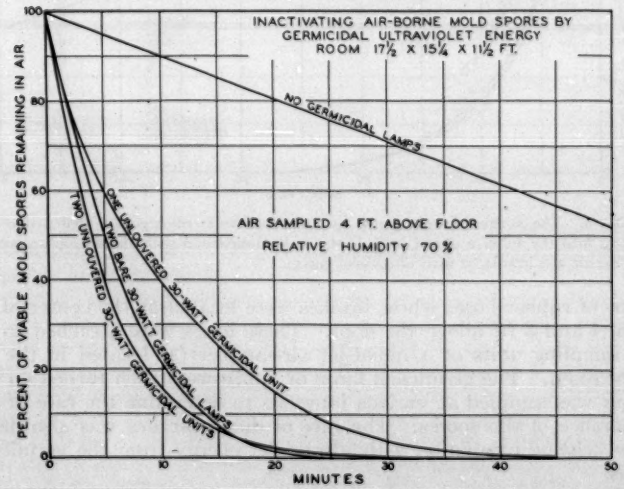

FIG. 8. Comparing the air disinfection rates achieved by three different methods of using the germicidal lamps. Almost identical results were obtained with two bare 30-watt lamps at the center of the room and with upper-air irradiation with two unlouvered units (see Fig. 5). The latter can be safely used during occupancy of the room.

most of the tests the air circulation was not forced but was that produced normally by the temperature gradients produced by the cold windows, a warm radiator, and the lamps used for illumination. In Fig. 6 are shown results of sampling at levels 4 and 8 ft. above the floor, when the relative humidity was 70. This high value of humidity was obtained by heating water on a hot plate which also probably aided air circulation. The fact that the disappearance curves at levels of 4 and 8 ft. are practically identical indicates appreciable air movement, since the intensity of germicidal energy was much greater at 8 feet than at 4 ft.

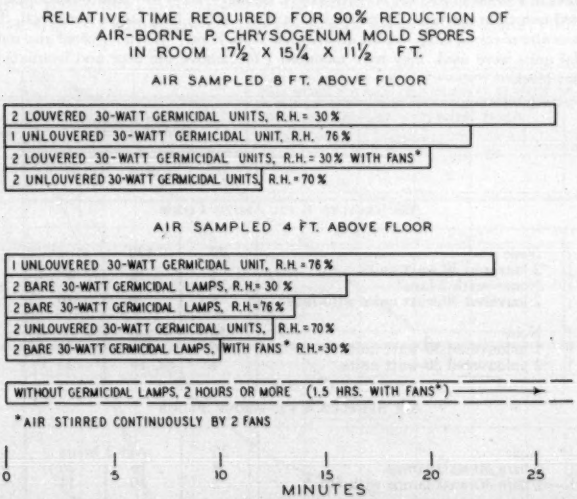
RELATIVE TIME REQUIRED FOR 90% REDUCTION OF
AIR-BORNE P. CHRYSOGENUM MOLD SPORES
IN ROOM 17½ X 15¼ X 11½ FT.
AIR SAMPLED 8 FT. ABOVE FLOOR
2 LOUVERED 30-WATT GERMICIDAL UNITS, R.H. = 30 %
1 UNLOUVERED 30-WATT GERMICIDAL UNIT, R.H. 76 %
2 LOUVERED 30-WATT GERMICIDAL UNITS, R.H. = 30% WITH FANS*
2 UNLOUVERED 30-WATT GERMICIDAL UNITS, R.H. = 70 %
AIR SAMPLED 4 FT. ABOVE FLOOR
1 UNLOUVERED 30-WATT GERMICIDAL UNIT, R.H. = 76 %
2 BARE 30-WATT GERMICIDAL LAMPS, R.H. = 30 %
2 BARE 30-WATT GERMICIDAL LAMPS, R.H. = 76 %
2 UNLOUVERED 30-WATT GERMICIDAL UNITS, R.H. = 70 %
2 BARE 30-WATT GERMICIDAL LAMPS, WITH FANS* R.H. = 30 %
WITHOUT GERMICIDAL LAMPS, 2 HOURS OR MORE (1.5 HRS. WITH FANS*)
*AIR STIRRED CONTINUOUSLY BY 2 FANS
0
5
10
15
20
25
MINUTES

FIG. 9. A summary of disappearance rates of air-borne mold spores obtained by various methods of irradiation with ultraviolet energy of λ2537.

Figure 7 indicates an appreciable acceleration of the clean-up of air-borne spores when a fan was used to increase air circulation. In a closed room, such as this was, there is little control of air circulation unless fans are used. Consequently, the results shown without fans appear to be conservative, since there would usually be a greater degree of air circulation in an occupied room, especially with doors partially open and more or less activity on the part of the occupants.

In Fig. 8 the results obtained when using one or two unlouvered 30-watt germicidal units irradiating the upper air are compared with the results obtained when irradiating the air throughout the room with two bare lamps. The two unlouvered fixtures produced slightly better

results than the two bare lamps. This surprising outcome shows the feasibility of irradiating the upper air of an occupied room to reduce the possibility of contamination by mold spores. The authors have already proved that this type of air irradiation will greatly reduce air-borne respiratory organisms. Consequently, in areas where food processing is being done by a number of workers, the germicidal lamps can be used for simultaneous protection of personnel and products.

TABLE II

Time required for definite percentage reductions of air-borne *Penicillium chrysogenum* mold spores in a room 17½ × 15½ ft. with 11½ ft. ceiling. Data for natural reduction rate and accelerated reduction produced by germicidal lamps. When bare lamps were used, they were placed in center of room, lamp centers about 4 feet from floor. When louvered and unlouvered germicidal units were used, they were mounted 7 feet above the floor and irradiated the air above that level.

Relative Humidity, %	Germicidal Sources	Time for Indicated Reduction, min.			Reduction in 2 hr., %
		50%	90%	99%	
	AIR SAMPLED 8 FT. ABOVE FLOOR				
30	None	23	120	—	90
	2 louvered 30-watt units	4	26	60	
	None—with 2 fans*	17	90	—	97
	2 louvered 30-watt units with fans*	4	20	30	
70	None	30	—	—	
	1 unlouvered 30-watt unit	6	22	40	
	2 unlouvered 30-watt units	4	13	23	
	AIR SAMPLED 4 FT. ABOVE FLOOR				
30	None	26	over 2 hours		87
	2 bare 30-watt lamps	4	16	26	
	2 bare 30-watt lamps with fans*	2	10	14	
70	None	52	over 2 hours		85
	2 bare 30-watt lamps	5	13	21	
	2 unlouvered 30-watt units	4	12	25	
	1 unlouvered 30-watt unit	7	23	39	

* Fans stirred room air continuously during test period.

In Fig. 9 is presented a summary of results of many tests under various conditions. It shows that whereas two hours or more were required for disappearance of 90 per cent of the air-borne spores without germicidal lamps, this time could be reduced to 10 to 26 minutes with germicidal lamps. In Table II the data are summarized more completely.

It will be noted from Table II that the unlouvered fixtures (see Fig. 5) were appreciably more effective than those with louvers. The louvers are desirable when the fixtures are used in rooms with low

ceilings, so that the energy can be principally concentrated in a beam with axis not more than 10 to 15 degrees above the horizontal. The purposes of the louvers are to prevent excessive intensities of germicidal energy below the level of the fixture and to keep the energy reflected from the ceiling at a minimum, since sufficient dosages of this radiant energy will produce conjunctivitis and erythema (reddening of the skin). However, the louvers absorb energy and reduce the total output of germicidal energy by the fixture.

The high rate of inactivation of air-borne respiratory organisms (from nebulized saliva) due to irradiation with germicidal energy as compared with the inactivation of air-borne mold spores is clearly illustrated in Fig. 10 which shows the results of tests in the same room.

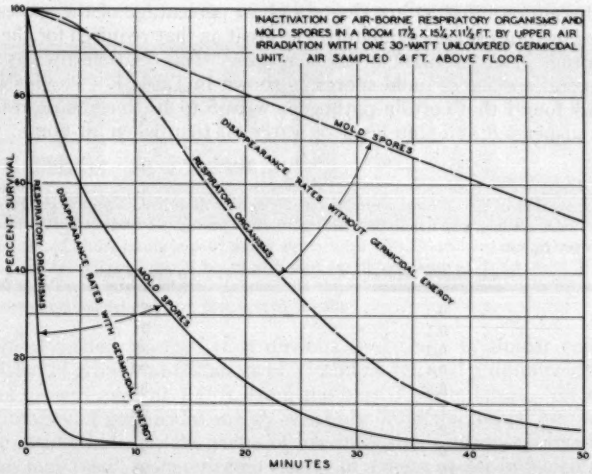
INACTIVATION OF AIR-BORNE RESPIRATORY ORGANISMS AND MOLD SPORES IN A ROOM 17½ X 15¼ X 11½ FT. BY UPPER AIR IRRADIATION WITH ONE 30-WATT UNLOUVERED GERMICIDAL UNIT. AIR SAMPLED 4 FT. ABOVE FLOOR.
PERCENT SURVIVAL
MINUTES
MOLD SPORES
RESPIRATORY ORGANISMS
DISAPPEARANCE RATES WITHOUT GERMICIDAL ENERGY
DISAPPEARANCE RATES WITH GERMICIDAL ENERGY

FIG. 10. Relative inactivation rates for respiratory organisms (from nebulized saliva) and mold spores by upper-air irradiation in a closed room without forced air circulation.

The room in which these tests were made has a waxed linoleum floor. Petri dishes attached to the ceiling, walls and floor showed that spores settled on the floor but did not attach themselves to the walls and ceiling. Several attempts were made to put them back into the air after they had settled on the floor (germicidal lamps off) by the use of fans vigorously blowing air against the floor. No increase in air-borne spores could be detected after this procedure, although culture media poured on the floor showed large numbers to be present. Experimental evidence seems to indicate that they are held on the linoleum by an electrostatic charge.

When upper-air irradiation was employed there was a small amount of germicidal energy diffusely reflected from the walls and ceiling. At the floor-level the intensity was about 0.3 microwatt per sq. cm. In one test this energy, applied over a period of about 20 hr., inactivated over 95 per cent of the dry spores of *Penicillium chrysogenum* on the floor. This important finding indicates that spores which settle out before inactivation may later be inactivated by prolonged irradiation with low intensities of germicidal energy. Hence air-disinfection for product protection can best be achieved by continuous operation of the lamps.

After the spores have settled on a surface or medium which will promote growth, they may be inactivated by a high intensity of germicidal energy acting for a short time, or by a low intensity continuously applied. Both of these methods were studied in these investigations. The dosage required to inactivate a given percentage of the spores on a culture medium is approximately $\frac{1}{3}$ as great as that required for the same percentage inactivation of air-borne spores. This relationship was found for several species of mold spores as shown in Table I. Previously the authors found that certain pathogens were 5 to 10 times more resistant when suspended in a thin layer of water (6) than when air-borne.

TABLE III

Inactivation of *Penicillium chrysogenum* spores on culture media as affected by elapsed time between seeding and irradiating with germicidal energy. Dosage was 300 microwatt-minutes per sq. cm.

Hours Elapsed Between Seeding and Exposure	Per Cent of Spores Inactivated
0	88
0.1	91
0.2	88
0.4	90
0.8	88
1.5	86
3	88
6	96
15	98
24	84

It is reasonable to expect that a spore will be more resistant to germicidal energy in the dry, dormant state than it will be in the vegetative, growing state. Consequently, it appeared important to study the effect of a definite dosage when applied to seeded plates at varying time intervals after seeding. A series of petri dishes was seeded by air-borne *Penicillium chrysogenum* spores drawn from the infection-chamber shown in Fig. 2, utilizing the duplex radial-jet sampler. In order to assure highest accuracy in the appraisal, one-half of each plate was exposed and the other half was used as the control. The results of this test are presented in Table III.

The variations in per cent inactivation during the first three hours are within the range of experimental errors. At 6 and 15 hr. the percentage was much higher, indicating a higher vulnerability in the early stages of growth. After 24 hr. there was slightly visible growth, and apparently a significant increase in resistivity.

The effect of *continuous* irradiation in inhibiting growth of *Penicillium chrysogenum* spores on a culture medium has been studied by exposing seeded plates at varying distances from a bare 30-watt germicidal lamp, in order to obtain a range of intensities of germicidal energy. Each dish was covered with a clear quartz plate masked around the edges to leave a clear central space two inches square. Paper numerals were attached to the quartz in the clear space, indicating the distance in feet between the lamp and the dishes. Continuous exposure for three days produced the results illustrated in Fig. 11 which is reproduced from photographs

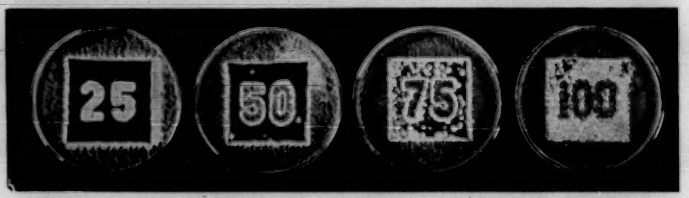

FIG. 11. Culture media in petri dishes were seeded with *Penicillium chrysogenum* spores, then exposed continuously for 72 hr. to a 30-watt germicidal lamp at distances of 25, 50, 75 and 100 ft. These results directly demonstrate the inhibition of mold growth by very low intensities of germicidal energy. (See text for details.)

of typical seeded plates. It is obvious that there is almost complete inhibition of growth at distances of 25 and 50 ft., and a definite retardation of growth even at 100 ft. from the bare 30-watt lamp. At 100 ft. the intenisty of germicidal energy was only 0.034 microwatt per sq. cm. These results indicate the value of low-intensity continuous irradiation such as may result from reflected energy in a meat cooler in which germicidal lamps are installed. The direct irradiation of air-borne spores in this case will inactivate many of them, and there is still the possibility of preventing spoilage by any spores that settle on the meats in locations where they receive low intensities of germicidal energy by indirect irradiation.

SUMMARY

Mold spores have their principal origins on decaying animal and vegetable matter, much of it outdoors. They are prevalent in outdoor and indoor air and cause great economic losses.

Spores can be killed or inactivated, that is, made incapable of reproduction, by irradiation with germicidal ultraviolet energy. The principal ways in which this may be accomplished are: (*a*) by high-

intensity irradiation of the air-borne spores; (*b*) by long continued low-intensity irradiation of the spores at rest on materials which do not support growth; and (*c*) by high-intensity short time or low-intensity long, continuous exposures of the spores on materials which promote growth.

FIG. 12. *Penicillium chrysogenum* mold spores were seeded over the entire area of the simulated ground around the miniature buildings and trees. The 2-watt germicidal lamp shown in the upper left-hand corner simulated a miniature sun. The germicidal energy inhibited the growth of the mold except in the protected areas or shadows cast by the miniature buildings, trees, etc.

The reciprocity law (Et = const.) has been proved to apply to both bacteria and spores over a range of intensity E of energy of λ2537 from 0.5 to 500 microwatts per sq. cm. and obviously a corresponding range in time t.

The range of resistivities of mold spores and bacteria to germicidal energy of λ2537 is commonly at least 1000 to 1.

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The inactivation of air-borne mold spores in a closed room using several types of installations of germicidal lamps has been studied. Without germicidal energy there was a 90 per cent reduction in air-borne spores, principally due to settling out, in about two hours. With the germicidal installations the same results were obtained in 10 to 25 min., depending on the system used. Most of the spores which disappeared were probably inactivated and were no longer potential sources of contamination.

A suitable installation of germicidal lamps can provide a high degree of air disinfection for the protection of personnel and products, without exceeding intensities safe for the eyes and skin of occupants of the room.

Continuous irradiation of products subject to mold contamination, even with intensities less than 0.1 microwatt per sq. cm., affords a high degree of protection from the molds used in these investigations.

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(4) MARSHAL W. JENNISON, "Atomizing of Mouth and Nose Secretions Into the Air As Revealed by High Speed Photography," Aerobiology Publication No. 17 of the American Association for the Advancement of Science, 1942.

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Mobile Cashier Unit (*American Gas Association Monthly*, Vol. 31, No. 9).—A mobile cashier unit at which consumers in outlying communities can pay their utility bills conveniently is the latest addition to the vehicular fleet of Consolidated Edison Co. of New York, Inc. The new unit is being used exclusively in New York City's borough of Queens.

The mobile cashier, which began its service on July 1, 1949, stops once a month at specified locations in 21 different Queens communities. Nineteen of these are full-day stops, from 9:30 a.m. to 4:00 p.m.; the other two are half-day stops.

Locations were selected specifically to include those communities that are farthest away from any district offices, and from which transportation to district offices is least satisfactory. Residents in these communities can save time and expense by paying their bills regularly at the mobile cashier.

This new service was brought to the public's attention through circulars distributed with consumers' bills, local newspaper advertisements and newspaper releases.

The mobile cashier is operated by commercial relations department personnel and is staffed at all times by a minimum of two cashiers. Continuous year-round service will be provided except for possible limitations during the winter in the event that heavy snows hinder curb-side parking.

The mobile cashier truck has a standard Chevrolet forward control chassis equipped with a Grumman aluminum alloy Kurb Side body. Interior office space, located to the rear of the driver's seat, provides an area 128 inches long, 78 inches wide and 70 inches high.

Exterior of the truck is attractively colored red and white with grey paneling. It has two cashier-type windows on each side so that it can operate on either side of the street. When it pulls to the curb at any of the designated locations, the two cashiers on duty take their places at the windows facing the sidewalk and are ready for business.

A wide aluminum panel, faced with a promotional poster, obscures the windows on each side while the unit is in transit. When it is on location, the windows facing the sidewalk are exposed by raising this panel, which then provides an awning effect over the windows. Dates on which the unit will return to a location for the next two months are included in the receipt stamp imprint which leaves a picture outline of the truck on each bill stub when payment is made.

Interior facilities have been designed to meet all contingencies. Counter-desks extend the full length of each side wall, with seating space at each window, and include the necessary storage space and cash drawers to meet the requirements of each cashier at his pay window. Three movable stools can be used wherever needed.

Ventilation is supplied by two fans and there is a compact heating unit ready for use during cold weather. The roof and both sides are fully insulated and the smooth plate floor is covered with linoleum. Four dome lights give the necessary interior lighting.

Standard cashier's working equipment is provided, including a safe, two coin change machines, two adding machines and a portable typewriter.

THE BASIS FOR THE OPTIMUM AIDED-TRACKING TIME CONSTANT

BY

E. A. MECHLER,[1] J. B. RUSSELL [2] AND M. G. PRESTON [3]

ABSTRACT

This report explains why the optimum aided-tracking time constant for continuous signaling is between 0.2 and 0.8 seconds. The general formulae for aided tracking are developed and it is proven that with intermittent signaling the optimum aided-tracking time constant should equal the interval between signals.

I. INTRODUCTION

It isn't much of a trick to track a slow-moving target with a shotgun or a telescope. Under such circumstances the position of the gun or telescope is adjusted continually by the hunter to match the position of the target. The operation is called direct tracking. When the speed of the target increases, the interval available to get on target becomes shorter and the rapid motion makes the target increasingly difficult to follow.

We can help the gunner move his gun by driving it with a motor and so arrange the mechanism that he may turn the motor speed control to adjust the velocity and position of the gun until it matches the velocity and position of the target. This is called velocity tracking. Once the gunner obtains a match, he need not move the speed control unless the velocity of the target changes. And when changes are smooth and gradual, he can follow them by small movements of the speed control.

Sometimes it is difficult to get on the target with velocity tracking. To overcome this difficulty, a combination of direct and velocity tracking is used. The operator moves the gun until it points at the target. Through gearing, this direct gun motion also turns the motor speed control and so adjusts the velocity of the gun that it matches the target speed. This is called aided tracking. Theoretically the gun follows a constant velocity target without further adjustment. But in practice, more than one adjustment is required as a rule before the gun and target velocities and positions match continuously.

The procedure is simple and the tracking is stable. With aided tracking, the gunner can get on target quickly and easily, and, once on target, no adjustments or at the most only small adjustments to the

[1] Research Engineer, The Franklin Institute Laboratories for Research and Development, Philadelphia, Penna.

[2] Professor of Electrical Engineering, Columbia University, New York, N. Y.

[3] Professor of Psychology, University of Pennsylvania, Philadelphia, Penna.

gun position are necessary to follow usual target motions. To achieve aided tracking, a ball and disk integrator can be used to combine the position and velocity adjustments into a single control.

The ratio between gun displacement per unit control displacement and gun velocity per unit control displacement must be properly chosen. This ratio, called the aided-tracking time constant, is expressed in seconds. It gives the time required for the motor to rotate the guns through an arc which is equal to the arc of the initial displacement. This report develops the theoretical basis for choosing the proper aided-tracking time constant.

During the war a number of laboratories, interested in the study of aided tracking, reported that the most favorable aided-tracking time constant was in the region between 0.2 seconds and 0.8 seconds. This fact was reported by The Franklin Institute in investigations using aided tracking in the control of aircraft turrets, and by other United States and English investigators. Throughout all of these investigations in which different mechanical controls were involved and in which different target and gun velocities were used it was a striking fact that the optimum aided-tracking time constant was not less than 0.2 seconds and not more than 0.8 seconds. The investigators agreed also that within the range 0.2 to 0.8 seconds the choice of constant made little difference. Many control mechanisms were developed using the median aided-tracking time constant of 0.5 seconds or thereabout.

Despite the unanimity in opinion as to the range of optimum aided-tracking constant, for continuous signals and its applicability to a wide range of tracking situations, little progress was made in discovering why the optimum constant was of the order of 0.5 seconds.

Recently the Franklin Institute Laboratories for Research and Development undertook to design an aided-tracking system for intermittent signals. The achievement of this project is an interesting example of setting out to investigate one thing and succeeding in discovering something substantially more important. The authors were undertaking to determine the aided-tracking time constant for intermittent signals, the limits over which stable tracking could be achieved with any one constant, and the best constant for a particular time interval between signals. There was no intention, particularly at the beginning of the study, of ascertaining why the aided-tracking time constant is of the order of 0.5 seconds for continuous signals.

Nevertheless, this investigation shows why this is so, and the explanation is sufficiently basic and essential that it can be applied widely to all types of aided tracking using continuous and discontinuous signals.

II. THE PROBLEM

The problem of tracking a target appearing at regular intervals on a radar screen imposes some new factors on the conventional aided-tracking problem solved during the war for aircraft and coastal defense

gunnery. Most significant is the fact that the target appears only once during every antenna rotation. Its spot on the PPI scope remains for a few seconds due to persistence of the cathode ray tube screen and then fades out.

The presentation as shown on a north stabilized PPI scope is depicted in Fig. 1. Here the bearing of the pip on the screen is determined by the azimuth position of the target with respect to the aircraft which contains the radar set. A brightened sector containing cross hairs can be moved about on the PPI screen. The angular position of this sector is determined by the angular position of the azimuth shaft. In turn an aided-tracking device is used to turn and position the azimuth shaft. Range is obtained in a similar way.

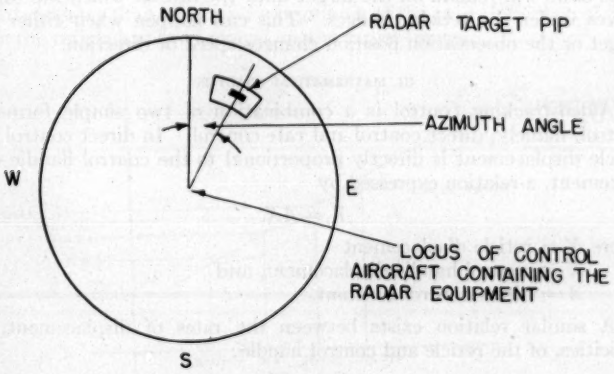

FIG. 1.

As a first approximation it may be assumed that the time intervals during which the target position is not observed are equal. One way to smooth these discrete target position data is to use aided tracking. The technique of tracking is to put the reticle quickly on the radar pip when it appears and then to make no further adjustment until the radar pip appears again.

The problem is to determine the optimum aided-tracking time constant which should be used in tracking this intermittent signal.

By definition, for a given rotation of the tracking knob,

$$\text{The aided-tracking time constant} = \frac{\text{Change in position of the reticle}}{\text{Rate-of-change in position of the reticle}}$$

If the cross hairs are centered on the radar pip at the start of a constant interval of τ seconds and the tracking rate is correct, the cross hairs will be centered on the radar pip at the start of the next τ second interval. If the rate is not correct the cross hairs will lead or lag the

pip by an amount $A°$. Assuming constant target and cross-hair rates, the error in the cross-hair rate is A/τ degrees per second. Thus, to track perfectly, a deflection of the tracking knob must change the position of the cross hairs by $A°$ and the rate at which the cross hairs move, by A/τ degrees per second.

To do this the aided-tracking time constant must $= \dfrac{A°}{(A/\tau)°/\text{sec.}} = \tau$ seconds. Consequently, when tracking a constant-rate target which appears at fixed time intervals, the aided-tracking time constant should equal the time interval in seconds. Theoretically this produces perfect tracking, and, when using this time constant, the cross hairs need to be positioned on the radar pip at only two successive intervals. Then the cross hairs will remain on the target until the rate at which the target moves under the reticle changes. This can happen when either the target or the observation position changes speed or direction.

III. MATHEMATICAL ANALYSIS

Aided-tracking control is a combination of two simple forms of control, namely, direct control and rate control. In direct control the reticle displacement is directly proportional to the control handle displacement, a relation expressed by

$$Y = AX \tag{1}$$

where Y = reticle displacement
X = control handle displacement, and
A = direct control constant.

A similar relation exists between the rates of displacement, or velocities, of the reticle and control handle:

$$\dot{Y} = A\dot{X}$$

where $\dot{Y}$ and $\dot{X}$ are the time rates of change of Y and X, respectively. In rate control the rate of change of reticle displacement is proportional to the control handle displacement, a relation expressed by

$$\dot{Y} = BX$$

where B = rate control constant.

In aided-tracking control the two effects are superposed and a displacement of the control handle produces both a displacement of the reticle and a change in the rate of reticle displacement, resulting in a rate of change in reticle displacement given by

$$\begin{aligned} \dot{Y} &= A\dot{X} + BX \\ &= A\left(\dot{X} + \frac{B}{A}X\right) \\ &= A(\dot{X} + aX) \end{aligned}$$

where $A/B = 1/a$ = aided-tracking time constant.

In what follows A can be taken as unity without loss of generality since it represents the gear ratio between the control handle and the rest of the system. Therefore, the choice of aided-tracking time constant will be studied using the relation

$$\dot{Y} = \dot{X} + aX.$$

Let the interval between target observations be τ and the actual target motion be $f(t)$. Then at the end of n such intervals the target position will be $f(n\tau)$. At this instant of time, $n\tau$, the reticle is placed on the target image thus making (see Fig. 2)

$$Y_{(n\tau+)} = f(n\tau+). \tag{2}$$

The $+$ is used to show that the relation holds for an instant of time slightly greater than $n\tau$ or at the beginning of the $(n+1)^{st}$ interval just after the reticle has been placed on the target image.

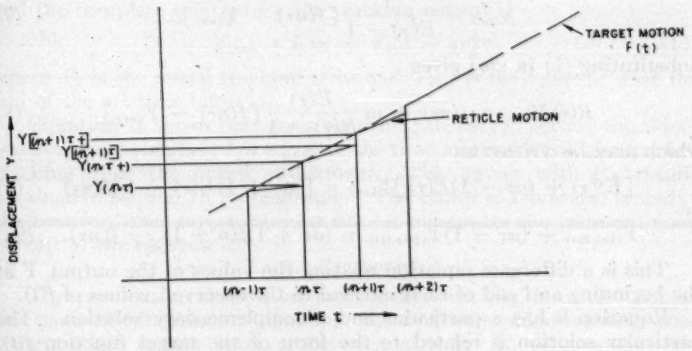

FIG. 2.

The value of Y at the end of this interval is

$$Y_{[(n+1)\tau]} = Y_{(n\tau+)} + aX_{(n\tau+)} = f(n\tau+) + \tau aX_{(n\tau+)} \tag{3}$$

where $X_{(n\tau+)}$ = control handle position after adjustment has been made at $n\tau$.

For ease in manipulation the operator $E(\tau)$ will be used where $E(\tau)$ shifts the time position of a function as shown below:

$$E(\tau)f(t_1) = f(t_1 + \tau),$$
$$E(\tau)Y_{(n\tau)} = Y_{(n\tau+\tau)} = Y_{[(n+1)\tau]}. \tag{4}$$

Using this in Eq. 3 gives

$$E(\tau)Y_{(n\tau)} = f(n\tau+) + \tau aX_{(n\tau+)} \approx f(n\tau) + \tau aX_{(n+1)\tau} \tag{5}$$

since X is the same at both ends of the $(n+1)^{st}$ interval and $f(n\tau) \approx f(n\tau+)$ because the value of the function changes only a very small amount during the adjustment of the control handle.

This may be written as

$$E(\tau)Y_{(n\tau)} \approx f(n\tau) + \tau a E(\tau)X_{(n\tau)}. \tag{5a}$$

It should be noted that $Y_{(n\tau)} \neq Y_{(n\tau+)}$ and $X_{(n\tau)} \neq X_{(n\tau+)}$ since X and Y are both suddenly changed at $n\tau$.

The change in X which must be made at each observation is equal to the error which exists at that time. Thus, at the end of the n^{th} interval of time or at $t = n\tau$

$$\Delta X_{(n\tau)} = X_{(n+1)\tau} - X_{(n\tau)} = f(n\tau) - Y_{(n\tau)}$$

and thus

$$E(\tau)X_{(n\tau)} - X_{(n\tau)} = f(n\tau) - Y_{(n\tau)}. \tag{6}$$

This gives

$$X_{(n\tau)} = \frac{1}{E(\tau) - 1}[f(n\tau) - Y_{(n\tau)}]. \tag{7}$$

Substituting (7) in (5a) gives

$$E(\tau)Y_{(n\tau)} = f(n\tau) + \tau a \frac{E(\tau)}{E(\tau) - 1}[f(n\tau) - Y_{(n\tau)}] \tag{8}$$

which may be written as

$$[E^2(\tau) + (a\tau - 1)E(\tau)]Y_{(n\tau)} = [(a\tau + 1)E(\tau) - 1]f(n\tau) \tag{9}$$

or

$$Y_{([n+2]\tau)} + (a\tau - 1)Y_{([n+1]\tau)} = (a\tau + 1)f(n+1)\tau - f(n\tau). \tag{9a}$$

This is a difference equation relating the values of the output Y at the beginning and end of each interval to the observed values of $f(t)$.

Equation 9 has a particular and a complementary solution. The particular solution is related to the form of the target function $f(t)$. The complementary solution is a transient and its form is independent of $f(t)$, but its magnitude depends on the conditions at the start of tracking.

To find the complementary solution $Y_{c(n\tau)}$, let

$$Y_{c(n\tau)} = Ce^{bn\tau}. \tag{10}$$

Substituting in the complementary equation

$$[E^2(\tau) + (a\tau - 1)E(\tau)]Y_{(n\tau)} = 0 = [E(\tau) + (a\tau - 1)]Y_{(n\tau)} \tag{11}$$

gives

$$[E(\tau) + (a\tau - 1)]Ce^{bn\tau} = 0,$$

$$Ce^{b(n+1)\tau} + (a\tau - 1)Ce^{bn\tau} = 0, \tag{12}$$

and

$$e^b + (a\tau - 1) = 0$$

which gives

$$e^{br} = (1 - a\tau).$$

Thus from Eq. 9 the complementary solution is

$$Y_{c(n\tau)} = C(1 - a\tau)^n. \tag{13}$$

This equation shows that for $0 < a < 1/\tau$ the complementary solution approaches zero as time increases and does not change sign. For $1/\tau < a < 2/\tau$ the complementary solution also approaches zero but the terms alternate in sign. For the case where $a = 1/\tau$ the complementary solution is always zero, and this is probably the best choice of a. For $a > 2/\tau$ the complementary solution diverges. Thus for practical operation $0 < a < 2/\tau$.

For the case in which the target is moving at a constant rate K, the target position at each instant of observation will be

$$f(n\tau) = K(n\tau) \tag{14}$$

and the complete solution for the tracking output is

$$Y_{(n\tau)} = Kn\tau + Y_0(1 - a\tau)^n \tag{15}$$

where Y_0 is the initial tracking error and $Y_{(n\tau)}$ is the value of Y at the end of the n^{th} time interval.

Equation 15 shows that, for a constant rate target, setting the aided-tracking time constant $1/a$ equal to the time interval τ will give perfect tracking after the initial adjustment. This agrees with the results obtained in Section II, by reasoning. The choice of $1/a$ is also probably the best for other target motions since it eliminates the transient component of the response.

IV. CONCLUSIONS

The previous sections show that, where tracking is carried out on the basis of intermittent signaling, the optimum aided-tracking time constant will be the interval between signals. If, for example, the interval between signals is 10 seconds, the optimum aided-tracking time constant should be approximately 10 seconds. If on the other hand the interval between signals is 5 seconds, the optimum aided-tracking time constant should be 5 seconds. Clearly these facts suggest very strongly that the appearance of an optimum aided-tracking time constant in the neighborhood of 0.5 seconds with continuous signaling of the kind used at The Franklin Institute during the war, at the Foxboro Manufacturing Company, and at other places, may result from the operator treating a continuous signal as if it were a discontinuous signal with a silent interval of approximately 0.5 seconds. This conclusion finds accessory support from the well-established fact that visual attention is always discontinuous, never continuous,[4] as well as from the

[4] For a consideration of this fact, see "Experimental Psychology," by R. S. Woodworth, published by Henry Holt, pages 696–704.

fact that reactions are subject to refractory phase, that is, once we have made a certain response it cannot be repeated until a short interval of time has elapsed. Operators of tracking mechanisms undoubtedly are attending with blank intervals of from 0.25 to 0.75 seconds, as a consequence of which, even with continuous signaling, they are in a situation analogous to discontinuous signals with time intervals of this magnitude.[5]

When the aided-tracking time constant exceeds the time interval between signals (assuming it to be constant) the tracking with a capable operator will be stable and the transient component of error will decrease slowly and asymptotically to zero. If the aiding ratio has a value between the duration of the interval and half the duration of the interval, tracking will be stable and the transient component of the error will exhibit a damped oscillation around zero. If the aided-tracking time constant has a value less than half the time interval, the tracking is unstable and the error will increase indefinitely. When the aided-tracking time constant equals the time interval, tracking is nearly perfect, and errors are due mainly to variations of the rate at which the target moves under the reticle.

[5] An extensive discussion of the fact that discontinuous corrections are habitually superimposed upon a continuous motion is contained in the following two papers:

K. J. W. CRAIK, "Theory of the Human Operator in Control Systems": "I. The Operator as an Engineering System," *British Journal of Psychology*, Vol. 138, pp. 56–62 (1947); "II. Man as an Element in a Control System," *Ibid.*, Vol. 138, pp. 142–148 (1948).

NOTES FROM THE NATIONAL BUREAU OF STANDARDS *

CALIBRATION OF PHOTOGRAPHIC LENS MARKINGS

In the course of an experimental study of errors in the speed markings of photographic lenses, scientists in the optical instruments laboratory of the National Bureau of Standards have devised a convenient graphic method for converting each of these markings for a given lens to the corresponding "effective *f*-number"—an *f* number corrected for light losses within the lens. In this way it is possible to calibrate a lens so that losses of light from absorption, reflection, and scattering within the lens are taken into account, and a more accurate control of the amount of light admitted to the exposed film is obtained.

The method now in use for speed marking of lenses is based entirely on the ratio of the equivalent focal length of the lens to the diameter of the aperture. This ratio—known as the *f*-number—gives no consideration to the great differences in the useful light transmitted by various lenses.

The Bureau has also developed a method of testing the marked diaphragm openings so that values that entirely compensate for differences in transmission can be obtained and applied to the scale of *f*-numbers on a photographic lens. In this system the markings, known as effective *f*-numbers or *t*-numbers, are obtained by means of a photoelectric cell and a relatively simple photometric procedure, in which the diaphragm of the lens to be calibrated is adjusted to transmit the same amount of light as a similarly placed opening of standard size. The standard opening corresponds to an ideal lens of a given aperture ratio, in which incident light is wholly transmitted. A complete calibration is obtained by the use of a series of openings of graduated size corresponding to various aperture ratio values.

ACTION OF BORON IN HARDENING STEEL

An investigation at the National Bureau of Standards of the hardenability of boron-treated alloys and steels has shown that the action of boron in increasing the hardenability is due entirely to a solid solution effect at heat-treating temperatures.

High-purity iron-carbon alloys were prepared for use in this investigation and several commercial and openhearth steels were used. Determinations of the hardenability of the alloys were made in terms of the "critical cooling rate," which is defined as the slowest rate at which the alloy or steel can be cooled and be completely hardened. The standard

* Communicated by the Director.

end-quench test was used for evaluating the same properties of the iron-carbon-manganese alloys and commercial steels. Specimens prepared from the alloys in the conditions as cast, as forged and homogenized, and as heat treated in various ways to precipitate a boron constituent were studied metallographically. Experiments were also made to determine whether boron was lost during the decarburization of commercial steels and for determining the rate of diffusion of boron in austenite of these steels.

The Bureau's results and those published previously strongly support the conclusion that the effectiveness of boron in enhancing the hardenability of certain steels is due entirely to its action while in solid solution in austenite. Only the portion of the boron that is in solution at the time of quenching contributes toward an increase in hardenability. The boron undissolved or in the form of compounds is either without effect, or possibly decreases hardenability by acting as transformation centers for austenite in the temperature range where pearlite is formed.

When boron enhances the hardenability of a steel, it decreases the rate of nucleation and not the rate of growth of ferrite and carbide. The boron atom, believed to be located interstitially in the gamma iron lattice, is effective in retarding either the rate of formation of nuclei or the rate of their growth to the critical size necessary for transformation to begin, or both.

V. 19

CAPACITANCE METHOD OF MEASURING WEAR

A convenient nondestructive method for measurement of the abrasive wear of textiles has been developed at the National Bureau of Standards as part of a program sponsored by the Office of the Quartermaster General, Department of the Army.

The method measures a property of the sample—namely, its capacitance—which is very closely related to the amount of material remaining in the portion of fabric tested. Since the specimen is not destroyed nor altered in any way during the capacitance measurement, a complete set of data may be obtained, showing the rate of abrasion at all times during the life of a single specimen.

The new method requires only three capacitance measurements to determine the extent of wear in a specimen over any interval of time. The electrodes of a precision capacitor are first adjusted to be slightly farther apart than the thickness of the thickest specimen to be studied. The capacitance C_a of the intervening air space is then measured. The capacitance C_0 with the unworn specimen between the electrodes is next obtained, and finally the capacitance C_R of the abraded specimen. The measure of destruction or ruin, Q, is then given in percentage by the formula

$$Q = \frac{C_0 - C_R}{C_0 - C_a} \times 100\%.$$

MAGNETIC MOMENT OF THE PROTON

The magnetic moment of the hydrogen nucleus, or proton, has been accurately determined in absolute units in the atomic physics laboratory at the National Bureau of Standards. When combined with other data, this work gives a precise absolute value for the electron charge-to-mass ratio, e/m. The gyromagnetic ratio of the proton, from which the magnetic moment was obtained, has been accurately determined by measuring the magnetic field and radio frequency required for magnetic resonance absorption in a proton sample. This is the first precise determination of the proton moment in absolute unit; all previous measurements approaching this precision have been made in terms of the relative values of other physical constants.

The new measurement provides an accurate secondary standard for magnetic fields. In the past, laboratory measurements involving both magnetic and electric fields have been limited by the low accuracy of the magnetic measurements. Now the situation is reversed, and magnetic fields can be measured more accurately than electric fields. This advance will be especially useful in the design and development of scientific and industrial apparatus employing magnetic fields where it is important to know accurately the special distribution of the field.

The nuclear resonance techniques developed in the course of this work can be applied to good advantage wherever the strength of a magnetic field must be regulated. The problem of magnetic field regulation arises widely in the use of scientific apparatus, such as cyclotrons, mass spectrographs, and beta-ray spectrometers, and in industrial equipment, such as servomechanisms and electromagnets.

EVALUATION OF PORCELAIN-ENAMEL TEXTURE BY A PLASTIC-REPLICA TECHNIQUE

A plastic-replica technique by which the texture of porcelain enamel may be conveniently studied and objectively evaluated has been developed at the National Bureau of Standards. The method of evaluation is based on the measurement of the haze of an ethyl cellulose replica of the enamel surface. Such replicas may be readily examined by either transmitted or reflected light, or projected for examination of the enlarged image. Details seen only with difficulty in the original surface are readily visible in the replica, which is a faithful reproduction of the surface texture. Another advantage is that the replica forms a permanent record for subsequent reference. By making a series of replicas during a test or service period, an investigator may follow the progressive breakdown of an enamel surface.

The replica technique should find application wherever small-scale surface roughness is evaluated. It can be used to classify surfaces as mat, semimat, or glossy, or to evaluate the degree of roughness de-

veloped in application of the enamel. It should lend itself readily to field inspections of enameled articles. Replicas made in the field can be examined by the investigator at his convenience, or sent to a central laboratory for study. A series of replicas of the same area of a test item, made before installation and after successive periods of service, will permit a study of the progressive breakdown of the surface. These replicas can later be compared with those from specimens treated in the laboratory to determine whether the laboratory test produces the type of damage observed in the field.

SKY COMPASS

The National Bureau of Standards has developed a sky compass, which indicates the direction of flight from which, with other data, the position of the aircraft can be determined. The compass is based on the investigations made by the late Dr. A. H. Pfund of Johns Hopkins University and is an outgrowth of his twilight sextant. The Pfund compass operates on the principle that the light of the sky during the day is partially plane polarized, the polarization being a maximum at right angles to the incident beam from the sun. The plane of polarization at any point in the sky thus contains both the observer and the sun. Establishment of this plane also gives direction, since it points to (or away) from the sun.

The principal advantage of the sky compass over the sun compass (which measures the direction of the sun directly) is its use during twilight, and when the sun is several degrees below the horizon, as well as when the region of the sky containing the sun is overcast, so long as there is a clear patch of sky overhead. The sky compass is thus of particular value when the sun compass and the sextant are not usable, after sundown before evening stars appear, and after morning stars disappear but before sunrise.

Essentially, the sky compass consists of an analyzer for determining the plane of polarization of the light, an azimuth circle on which the sun's computed azimuth can be set, and a clock that drives a chosen reference line in synchronization with the sun's apparent motion, that is, one revolution in 24 hours. For convenience in observing a portion of the sky around the zenith through the analyzer, the analyzed beam is turned from vertical to horizontal by means of a mirror.

PERFORMANCE OF PORTABLE ELECTRICAL INSTRUMENTS IN MAGNETIC FIELDS

Most portable instruments depend upon an internal magnetic field for their operation. A stray external field may, however, modify this internal field and make the instrument read incorrectly, particularly

when the external field is not taken into account. To determine the extent of such fields and how best to minimize their effects on voltmeters, ammeters, and wattmeters, an investigation of a representative group of commercial portable instruments was undertaken at the National Bureau of Standards. A brief study was also made of the stray field about some of the more common kinds of laboratory apparatus.

Magnetic fields of known magnitude, direction, and phase angle were set up about the test instruments by means of a pair of Helmholtz coils and suitable auxiliary apparatus. Auxiliary instruments, well-shielded and of high quality, were used as comparison standards. Placed well away from the Helmholtz-coil field, these instruments were read with a microscope of low magnification.

An analysis of the test results revealed that: (1) of eleven moving-iron-type instruments tested, seven exhibited field influence values within their accuracy figures in a 1-gauss field; in a 2-gauss field, four met this qualification; whereas none did in a 5-gauss field. (2) Of the seven permanent-magnet moving-coil instruments tested, two—having unshielded low-coercivity magnets—were affected by amounts comparable to their accuracy figures when subjected to fields of less than 1 gauss; and the other five—with high-coercivity magnets, or low-coercivity magnets combined with good shielding—behaved in a similar manner and could withstand 5-gauss fields or stronger without showing field influences greater than their accuracy figures. (3) Of seven electrodynamic instruments investigated, one (unshielded) in a 1-gauss field showed a field influence of 0.9 per cent, nearly equal to its 1 per cent accuracy figure; at 2 gausses the remaining six showed field influences less than their accuracy figures; while two of the six still met this qualification in a 5-gauss field.

The instrument itself (for most types) may be used to check the presence of harmful stray fields if its supply is sufficiently steady.

The Bureau's investigations show in general that the chief factor regarding the effect of stray fields on instruments lies in failure to recognize such effects and in not taking steps to avoid them.

THE FRANKLIN INSTITUTE

MUSEUM

The recent world war brought into prominence the problem of remote control in regard to the guidance of missiles and pilotless airplanes. The laboratories of The Franklin Institute played a not inconspicuous part in the solution of those problems. Meanwhile in numerous other laboratories other applications were being found for remote control and, after the cessation of hostilities we were suddenly confronted with a threat of a new science, that of cybernetics, in which the human being was surplanted in the performance of routine, repeated duties.

It is not, however, generally known except to Museum visitors that an interesting demonstration of an unconventional method of remote contol has been given daily in the Museum for over ten years.

In 1933 the late Thomas H. Dougherty of Wayne, while a voluntary worker on the staff, began to discuss with a colleague, William P. West, the project of building a remotely controlled boat. As a result of their consultations and that spirit of friendly cooperation which marks the staff relations, Dougherty began to construct a five-foot model of the 240-foot pleasure yacht *North Star*, while, at his request, West designed the mechanism which would permit the model to be manoeuvered in a manner very much like its prototype, both as to the operations performed and to the relative speed of response. After two years of work both men had completed their respective tasks. When the whole was assembled and tried out on a lake near Dougherty's home the two men had the satisfaction of seeing an excellent model yacht, complete in all its details and weighing forty-seven pounds, perform to near perfection in response to signals transmitted by the operator on the bank of the lake. So admirable was the accomplishment that only very few refinements were necessary to attain smooth and accurate control.

The boat is driven by a six-volt battery-powered motor and is steered by means of a motor driven rudder. The operation of both motors is controlled by a radio system which transmits through a telephone dial the number of impulses for any desired operation, and a stepping switch in the receiver which causes the correct relay to set in motion the manoeuver called for by the operator on "land." The stepping switch is a device widely used in telephone work. One impulse will cause circuit No. 1 to close, two impulses No. 2, etc. The transmitter is the push-pull type making use of a single type 19 tube. The frequency of transmission is in the five-meter amateur band, and the carrier is on the air continuously except during the transmission of the actual impulses.

Unhappily, Tom Dougherty's untimely death curtailed his enjoyment of and further experiment with the boat which he had projected with so much enthusiasm. However, many thousands of young people have delighted in its operation since Mrs. Dougherty presented the boat to the Museum. A special tank was built in the Marine Transportation Section and the boat is demonstrated here daily. Its popularity among the young and old visitors is apparent from the intense faces of the audience and from the numerous questions which are asked after each demonstration.

The remotely controlled boat is the final stage of man's development of his methods of transportation over water, the other steps of which are illustrated in the excellent series of models illustrating the progress made since the daring Norsemen set the prows of their longships in the direction of the West. But it is more than a symbol of man's conquest of the ocean. It is an example of the beginnings of that new science with the fearsome name of cybernetics of which we are likely to hear so much in the future.

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JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL during the next few months:

YU, Y. P.: Applications of Network Theorems in Transient Analysis.

WHITE, W. C.: Electronics—Past, Present and Future.

FREUDENTHAL, A. M.: Workhardening of Metals.

GRIFFITH, ROY T.: Minimotion Typewriter Keyboard.

JACOBSEN, LYDIK, R. L. EVALDSON AND R. S. AYRE: Response of an Elastically Non-Linear System to Transient Disturbances.

MOON, PARRY AND DOMINA EBERLE SPENCER: A Modern Approach to Dimensions.

FANO, ROBERT M.: Theoretical Limitations on the Broadband Matching of Arbitrary Impedances.

FANO, ROBERT M.: A Note on the Solution of Certain Approximation Problems in Network Synthesis.

SILBERSTEIN, LUDVIK: Developable and Developed Silver Halide Grains.

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THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

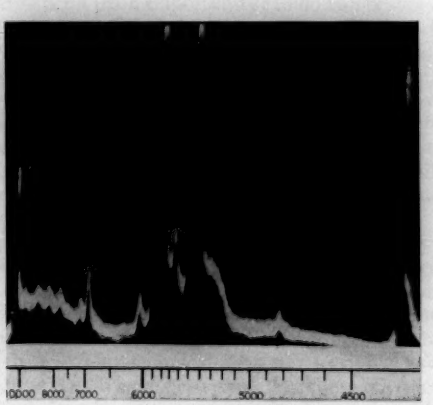
Abstract of **The Image Orthicon in Spectroscopy.**[1]—R. E. BENN,[2] W. S. FOOTE,[2] AND C. T. CHASE.[2] Modern electronic techniques, applied to spectroscopy, not only enable one to

[1] Published in the *Journal of the Optical Society of America*, Vol. 39, No. 7, pp. 529–532, July, 1949. Based on work performed under contract with the Office of the Chief of Ordnance, Department of the Army.

[2] Research Engineers, and Assistant Director, respectively, Chemical Engineering & Physics Division, The Franklin Institute Laboratories for Research and Development, Philadelphia, Penna.

overcome certain limitations of the photographic plate or film; they also make possible the instantaneous observation or recording of spectral intensity as a function of both wave-length and time throughout a wide spectral region. One such application, in which the image orthicon replaces the photographic plate in the spectrograph, is discussed.

The image orthicon, RCA Type 2P23, is a recently designed television pick-up tube having high luminous sensitivity in the approximate range 3500Å to 10,000Å, with a peak in sensitivity near 4200Å. As a detector in spectroscopy the tube has a number of advantages of which three are outstanding: (1) For short exposure times it is much more sensitive to light of low intensity than any available photographic emulsion, since its signal-to-noise ratio is considerably greater than the ratio of density to background for the plate under these conditions; (2) It is sensitive not only in the visible region but also in the near-infra-red region; and (3) It can be made to respond to illumination, and provide a corresponding signal response, at any unpredetermined instant or succession of instants, and it exhibits, over fairly short times, a cumulative characteristic which for short exposures to weak illumination may be more linear than is the case for the photographic plate.



Engraving loaned through the courtesy of the Journal of the Optical Society of America.

Mercury spectrum as observed with recurrent sweeps on the orthicon spectrograph. (A scale of wave-lengths in angstrom units is attached.)

The output signal appears on an oscilloscope as a curve of intensity vs. wave-length in any range up to the limits, 3500Å and 10,000Å, imposed by tube sensitivity. If more than one signal is desired, a number of traces, separated in time by small predetermined amounts, may be photographed by means of a high-speed camera, or separated on the oscilloscope screen and photographed in a single exposure. This feature is of particular value in the study of rapidly varying or transient sources, especially where the illumination is so faint that a moving plate or film cannot be used in the spectrograph.

The application of the orthicon to spectroscopy was originally made in order to study a gaseous combustion process in which a few prominent spectral lines and bands were available. The time variation of the intensities of these lines and bands, unobtainable in many cases on a moving plate or film because of low intensities, is observable with ease and accuracy. Preliminary work of this nature has already been reported.[3] With this technique it should be

[3] AGNEW, FRANKLIN, BENN, AND BAZARIAN, *J. Opt. Soc. Am.*, Vol. 39, p. 409 (1949).

possible to follow the course of a chemical reaction where certain radicals are free and active only during the reaction, and are not available or detectable before or after the reaction.

Preliminary observations indicate that for short exposure times the orthicon is about fifty times more sensitive than the photographic plate, if the orthicon response is measured above noise and the plate response above background. The orthicon has the further advantage that the entire region between 3500Å and 10,000Å can be covered at the same time—no single photographic emulsion will provide this coverage. Errors due to the use of several plates of different types, especially if used at different times, or to low sensitivity in the overlap regions, are thus avoided.

NOTE: Reprints of above paper are available in limited quantities. Address: Administration Division, The Franklin Institute Laboratories for Research and Development, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pa.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

The Changing Face of Research.—ELLICE MCDONALD, Director. In one lifetime, all arrangement of life has changed and it would be surprising if research, which is so much responsible for that change, should not have altered in its arrangement and orientation also. Perhaps research in itself is more responsible than anything for that change.

The pattern of life has altered. In one generation, standards have changed; there are no charts to guide the progress of present day affairs. All now must depend upon importunity: to do the best we can until we see how things break. Our fear is that, as a result of world affairs, less good things will result than the moderate good we had before and yet, as scientists, we can visualize a better arrangement than ever we had before, were we free to arrange for ourselves. Maybe this is our defect, but yet we are only slowly coming into our own: still confined and conflicted, made use of and depreciated by the ignorant politician or demagogue who has greater appeal and resource than the silent scientist, so long as people persist in classifying science as something apart from ordinary life.

Things have changed so in one lifetime that it is only in retrospect that we begin to appreciate how revolutionary the changes have been. It seems as though our advances in knowledge and technical capacity have gone so far ahead of our experience in government and control that there is a lag between them that will take a considerable number of years to catch up. Our technical advances in living, comfort, manufacture and general ease have been great, but there is a question whether the present deterioration of government inefficiency and honor has not depreciated all our effects, so that we are lagging rather than advancing in spite of all material progress. Certainly the cynicism of present day Statism (for that is what it is), seems a reaction and a rebuttal of all scientific efforts toward betterment. For why should we make such lifelong efforts toward the betterment and ease of mankind if a sign painter with a vogue for dramatic oratory was able to do more for destruction of the world than all the scientists have done to build it up? This man, incompetent, ignorant as he was, has changed the world and with it he has changed research. Or to put it in better words, the forces which allowed him to change the world had even before changed research.

These forces came of research. Such things would not have been possible forty years ago: all these are dependent upon research and discovery; good or bad as the results may be. Undoubtedly research in its passion for detail, precision and measurement has become a trifle

inhuman in the sense that it has not taken into account the low level of human appreciation. Scientists fulminate and adumbrate against present conditions to scientists, a limited group who are mostly inarticulate. The result does not touch the mass of the people who believe in headlines. Of course, one trouble with scientists is that they are trained to tell the truth and exact knowledge is a handicap to forcible statement. It is difficult for them to distort the truth, for their search is truth, and if they are in doubt, they modify their statements by so many qualifications that the final summary is denuded of its real value. They suffer from what a very interesting newspaper reporter once designated as "factism." They want to have such exact statement made that the main idea is obscured in detail: in other words, they are speaking to their fellows and, if we continue to speak to our fellow scientists, we cannot complain if our fellow scientists (and few of them) alone digest our statements. It is our own fault that we have not impinged more on the affairs of our own people to show them how management could be made useful. Minority pressure groups have usurped the place that the advice of scientists should have in affairs of government.

We have not even applied our principles to the most common incidents of life. The law of natural selection can only operate successfully with the law of natural elimination. We have done away with the latter with our intense preoccupation over lives that Nature will have none of by hospitals and welfare centers. This prudery and preoccupation of ours refuses to face an obvious fact and still less to put it into plain words. We give endless patience, trouble and thought to the breeding of our horses, cattle and dogs and none at all to the production of that infinitely more important man. The still small voice of science is drowned by the smooth speaking politician with his unlimited and irresponsible promises.

So research in spite of its great advances has lost out to the little people. Its defects were the faults of precision, exactitude and honesty and it must continue so if it is to be research, because the qualities of research are such that the last and most fatal ditch that any research man can fall into is to alter his results according to his need and away from the truth. This is so rare that in forty years of experience only one such has come under observation and he returned to "heil" the Hitler he then despised.

Research does not stir the soul of crowds like the preachers, Mohammed, Peter the Hermit, St. Paul, Luther and the other Pied Pipers. These subtle rhetoricians, seeking their own personal interests, endeavor to persuade by flattering base instincts and dwelling upon hardships and injustices. They then arouse in their hearers a faith which has always been the function of great leaders. It is not by students or philosophers, still less by scientific sceptics, that have been built the great movements

which have swayed the world. The researchers are too exact and too inarticulate.

One extraordinary thing is the poor quality of these leaders. Napoleon did not succeed immediately by his qualities and it was only an accident that he had such training as to develop him into a capable administrator. He had the capacity, as did Genghis Khan who was another great administrator and conquered most of the known world. However, the astonishing thing to scientists is the poor quality of human material that can sway the populace. Affirmation, pure and simple, kept free of all reasoning and all proof, seems to be one of the surest ways of making an idea enter the mind of the mass. The more concise the affirmation, the more destitute of every appearance of proof and demonstration the more weight it seems to carry. Thereafter, repetition and continued repetition induces a contagion and the uncertain basis of fact is lost and forgotten. The mass opinions are propagated by contagion, but never by reasoning, so that the scientist with his predilection toward exactitude and deduction has little influence upon world affairs, except as his discoveries can be useful to the politicians. When the scientist ceases to depend upon his results, then he loses his name. It is by word and not fact that crowds are moved.

The role of the research worker is not such as to wield immediate world influence, although his permanent influence on world affairs is greater than many of the ephemeral exploitations and explosions of the politicians which arouse in scientists a deep distaste and distrust.

However, after all that complaining, this is the world and we have to live in it. Some years ago, some of us tried to get a definition of sanity. In the group were two psychologists (whatever they are), one psychiatrist and a medical doctor. The best we could do was make a definition that sanity was "the degree of contact with reality." It takes one back to the two old Quakers—"All the world's queer but me and thee and I sometimes think thee a little queer."

In our time, however, the world has changed. It has changed in so many material ways that it is only by retrospect that we can appreciate the difference. The changes which have occurred can be listed under three heads:

1. Annihilation of distance
2. Scale of operations
3. Increased use of power.

These three, although very broadly stated, are at least, in part, the factors which have determined the enormous change in life in our time. Because this change has occurred within so short a time it is a little difficult to see in perspective. It has happened to us and the quick succession of events have followed in such sequence that they have overlapped and become a continuity, rather than being as the physicists say "particulate."

In the life history of lower organisms which can be studied in their various and succeeding generations on account of their shorter life span, succeeding generations will go along on an even keel of development and arrangement, so that each new organism maintains the character and resemblance of the previous parents. There then sometimes comes, from whatever unknown cause, a deviation from standard type and new generations of the organisms develop to a different type from their progenitors, so that the succeeding type of organisms is different from those which have gone before. This is called a "mutation period" where, in the course of evolution, the organisms, such as the drosophila or fruit fly for example, change their type.

In human affairs, this present time seems to be a mutation period for mankind. Such stirring events have happened in one man's lifetime of threescore years and ten that, if measured in events, such a man might consider himself to have lived perhaps 300 years rather than the allotted time of the Psalmist. The revolution of life cannot but have its effect upon the nature of man, although we may be too close to the picture to comprehend the vastness of the change.

What have these things to do with research? Has research altered as has life? Are these the product of research or does research advance result from the accumulated incidence of the discoveries of the last fifty years? As well ask, as the snow ball rolls and grows in size with accumulation, is it due to the momentum or to the adhesive qualities of the soft snow. Or is the hen before the egg which is before the hen which lays an egg. Incidentally, this last statement was debated by Aristotle.

Whatever the mechanism of the matter, there is no doubt that research has been profoundly altered, although some research workers do not yet see it, for, strange as it may seem, research men are sometimes the most conservative and reactionary of people although their sphere should be to do with new things.

Annihilation of distance and ease of communications have profoundly influenced research. Marconi has rendered research provincialism a migratory if not a meaningless thing. Physically, as a result of these discoveries, the continents are a thousand times closer together than were the scientists of a hundred years ago. The rapid dissemination of news makes all of us contemporary participants in the experiences of the whole world of science. A discovery is made and it is flashed around the world to be seized upon with eagerness by all those with research curiosity. "Let us check his conclusions and see if they can be verified." In almost no time, scientists are working, checking and developing the idea and applying it to their own problems.

After publication, the report arrives, perhaps in a day from Europe by transatlantic clipper, perhaps in a week by steamer. Details and methods are known and the whole world of science is instructed.

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If there is a new development, even a new theory, men flock to the originator for instruction. In 1926, there were twenty American physicists in Göttingen, where Born and Jordon had announced a new development in quantum mechanics. A year later, they were at Zurich with Schroedinger; a couple of years later with Heisenberg at Leipsig; then Dirac at Cambridge was the attraction. The scientist, and quite right, will, as Horace says, take honey from any man's hive. A personal journey to hear Bohr in 1919 gave me a sentence which altered my entire view of biological research. Bohr then had only the first model of the atom and he said, "From now on the face of science will be changed. We can now study from the minute to the mass instead of from the mass to the minute." It struck home to me that at that I had been studying the processes of life from the mass to the minute, down the branches of the tree instead of from the roots.

Men's minds are quickened and their imagination stimulated so that thought is released from the shackles of authority and traditional dogma. The annihilation of distance, the ease of communications, with the size of operations, combined to accelerate the progress of research to an extraordinary degree. An example of this is the check that has resulted on the statement of Kögl in Copenhagen that, in cancer, the form of the amino acids was different from that in normal tissue. The unnatural or unusual form of glutamic acid, the $d(-)$ form, for example, was said to be more preponderant in cancer tissue than the usual or natural $l(+)$ form.

This statement, if verified, might be of enormous importance and might point the way to the cure of cancer where chemical differences from normal are slight. It would involve a new set of enzymes from the normal, different forms of metabolism, new chemical configurations and new properties. This study was a difficult one, for one reason because it involved animal cancer and human cancer experience, biology, chemistry and physics, branches of science which do not so often come together. For another reason, the chemical methods were difficult and fraught with pitfalls.

However, the statement was seized upon by researchers in England and the United States and, within a year, such doubt was cast upon the results that there was no longer hope of its accuracy. Our own laboratory contributed no little part to this work. On viewing this event in retrospect of my experience, 20 years ago this check would have taken five years' time and then might have not been completed nor indeed could have been done at all at that time.

Such a circumstance as this depends not alone upon quickness of communication but also upon size of operations. There are so many more people working in such larger coordinated groups that scientific research must advance by leaps and bounds. Coordination of the sciences, physics, chemistry and biology, makes it possible to gain a

comprehensive view of a problem where the isolated methods of the part would give no answer, but only come to the impasse.

Size of operations applies not only to research groups but to the scientific societies which actually exist for the exchange of information. The big aggregations of incorporated capital are one example of the increase in the size of operation and they, by the possibility of cooperation of large numbers, have made possible advances, based upon research, which have revolutionized human affairs. The dread spectre of war itself enlarged the hideousness of its countenance by the masses which it employed.

In science, large numbers of men exchange information, discuss methods and check results. An example is the American Chemical Society with 60,000 members, two large meetings a year attended by ten thousand chemists, and more than two hundred and ninety minor or local meetings a year. Another example is the American Association for the Advancement of Science with about 33,000 members. The programs of these meetings are now so large that they have almost become unwieldy, but a mere glance over the printed list of papers is stimulating to the imagination and gives inspiration to the mind.

Another example of the increase in the size of operations is the collection of scientific literature and the great number of scientific publications which are in existence at present, compared to the few of fifty years ago. In the Biochemical Research Foundation, for example, we have besides books and bound volumes a reprint collection of 37,600 items collected over 20 years. These are indexed and cross indexed as to author and subject with a separate index under "methods". A cross section of all papers pertinent to our type of research is always easily available. It is much easier to take ten or twenty reprints from the files instead of as many bulky bound volumes. The reprints can then be sorted out and such as are required will come easily to hand. If these reports were in books, the bound volumes would have to be strewn over a room with each place marked and would not convey the same impression to the mind as a number of thin pamphlets, easily placed on one's desk to be taken up, studied, and sorted with such ease. This collection which has taken constant care, time and money to create is the most valuable single item in our laboratory and in case of fire, there is an order that it should be the first thing saved, for it is not replaceable.

As to the third category of *increased use of power*, this has its prototype in science in the vast numbers of instruments of precision which have been devised to aid the scientific observation. The number of these would require pages to enumerate and every day brings another. These increase the power of man by giving him tools to extend the value of his bodily senses, just as power, produced by heat or electricity, extends man's muscular power.

The development of a new apparatus in Sweden means its use in a few days in the U. S. A. Not only in precision, but in the extension of our organs of sense by microscopes, spectrographs, photographic applications, etc., all bring methods of accuracy and record to make new advances possible. Indeed, the mere necessity of such apparatus, most of which requires specialists, makes larger aggregations and cooperative work necessary and makes the lone-worker, the prima donna type, less effective. After all, the prima donna requires an opera company to support her genius.

A great deal of this advance has been due to development in physics. Until 1888, the physicists had really given up hope of increase in their knowledge of their science; all that was thought to be left was the elaboration of detail to the fifth decimal point. The knowledge of the visible frequencies was only a minute space in the whole spectral range. The discoveries by Hertz were the beginning, followed by Roentgen, Bohr, Hess, Millikan, Schroedinger, etc., and opened a new field in regard to matter and the structure of the atom.

Chemistry, physics, geology, astronomy and biology were conceived as parallel lines which might be infinitely prolonged without danger of meeting. Now all science is one. If chemical combination is the giving, taking and sharing of electrons, surely this makes it akin to physics. If life depends upon oxidation-reduction processes, these in turn must depend upon electron interchange. Biology, which includes the study of life and disease, on account of its many variables, has been the lagging phase, but with the advances of the recent past, it does not require much imagination to realize that in this branch are due future great discoveries. Its dawdling alone means that it must take up its slack.

These advances facilitate our work and are more than an omen, they are a cause of success. This is one of the pleasing surprises which often happen to active resolution, so that may things, difficult to design, by new tools prove easy of performance.

All this has been done without government subsidy and in the past Government agencies have had the criticism of taking others' work and exploiting it to bolster their claims for increased budgets. The real scientist looks with some trepidation to the plans for vast government subsidies and control of research. It is misleading to assume that expenditure is identical with efficiency. The commission form of operation is useless. It fixes neither responsibility nor authority and is deadly to initiative and enterprise which is the soul of research.

The argument for a planned and completely coordinated research program on a national scale is based on the rapid results obtained in the field of atomic fission, penicillin, other biotics, etc., by means of highly coordinated research efforts. However, an examination of the background of these problems shows that the rapid evolution was really in the field of *development* rather than in *research* and *discovery*.

The role of the exploiters was that of an *entrepreneur*, as Florey acted in the development of penicillin discovered by Fleming many years before.

However, in a field where no clearly defined line of approach can be said to exist it is doubtful whether a rigidly planned program would produce results more rapidly than the time-honored method of independent research activity, for discoveries are made by men, and if the free spirit of research is hampered, the vision is impaired. Discoveries are the unveiling of the unknown and so cannot be foretold in advance: if it were so, they would not be discoveries. A planned research tends to concentration in much detail in a few directions which are lucky if one succeeds in hitting the correct solution, an experiment and error type of research. Looked at in this light, the probability of hitting a correct solution is not so good.

The real scientist is a creative artist. No one must boss him or drive him. Certainly arrange that his life be free from monetary worries; but let us remember that his life interest and pleasure is research. Leave him to carry on undisturbed by the stormy blasts and distractions of a quarrelsome world licking its wounds after a terrific fight. Do not let him be regimented by the politicians, even those of his own class. Then, the upward curve of research and discovery can continue unhampered, which it will never do if the spirit and vision of research are not free for advance. These will come through the exceptional man and he is often quite unappreciated by those of bureaucratic tendencies. There is an old Scottish proverb, "Wha pays the piper, ca's the tune", and unless those who call the tune have a sympathy and understanding of the research instinct and the necessity for untrammelled development of its creative curiosity, the vast government subsidies will be worse than wasted.

The present is indeed an age of stupendous advance, but granting the utmost to the creative genius of our time, we should never have run our mile, but for the furlong achieved by the pioneers of science in the last three generations. The past is important, the future is exciting, but the present interests us because we live in it.

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BOOK REVIEWS

STRENGTH OF MATERIALS, by J. P. Den Hartog. 323 pp., illustrations, 16 × 23 cm. New York, McGraw-Hill Book Co., 1949. Price, $4.00.

Many books have been written on strength of materials but it is seldom that one covers the field as well, and still makes such interesting reading, as Den Hartog's newest book. It is written as a text for use in a first course in the subject. Wisely, certain sections are marked for omission if the teacher believes them too difficult. There are over 200 pages of text followed by 87 pages of problems. The problems are better than those generally found in similar texts in that they require real thinking on the student's part. Certainly some of them are beyond his capacity while studying the subject for the first time, but with the assistance of a good teacher they will broaden his thinking and improve his methods of attacking a problem.

The first three chapters are entitled Tension, Torsion, and Bending and cover the most important cases of stresses in beams and shafts. These are followed by a chapter on Compound Stresses where Mohr's Circle is introduced together with the maximum-stress, maximum-strain, maximum-shear-stress, Mohr, and maximum distortion energy theories. The next three chapters adequately cover beams of different types with various loadings and thin- and thick-walled cylinders.

There is an excellent chapter on Experimental Elasticity covering Photoelasticity, Strain Gages, and Fatigue. The student should find the section on the use of Resistance Strain Gages interesting and extremely valuable information. The problem of determining the magnitude and direction of the principal stresses at a surface point is solved by the use of a rosette of three strain gages. This gives strains in three directions, 120 deg. apart, and Mohr's circle is applied to determine the principal stresses and their direction.

Although this book was written as an undergraduate text, it is highly recommended, because of its easily readable style, for the engineer who would like to brush-up on the fundamentals of the subject.

WM. M. MORSELL

ABSORPTION SPECTROPHOTOMETRY, by G. F. Lothian. 196 pp., tables, drawings and illustrations, 14 × 23 cm. London, Hilger and Watts Ltd., 1949. Price, 26 s.

This book is, as the subtitle states, a "Manual on the measurement of absorption spectra in the ultra-violet, visible and infra red regions of the spectrum by photographic, visual and photoelectric methods" and is of practical value especially to less experienced workers. It is divided into three sections dealing respectively with general principles, typical applications of spectrophotometry and the technique of measurement.

The first part contains a brief resume of the development of work in this field. For those not familiar with modern physical theory, some theory is included on the production of line and band spectra. The laws governing absorption, the definitions and nomenclature involved are discussed and well illustrated. The conditions for securing accuracy are clearly set forth and practical suggestions and information given concerning the choice of dispersing media, lenses, detectors, etc.

The three chapters comprising part 2 deal in more detail with the applications of spectrophotometry to the study of molecular structure, to chemical analysis and to biological and biochemical problems. Again the reader is introduced briefly to modern theory as a basis for a clear understanding of the relation between absorption and chemical structure. The absorption maxima of various chromophoric groups in the ultraviolet is given and the influence of other added groups illustrated. Absorption of vibration-rotation bands in the infra red is considered and illustrated by series of curves of related compounds. The usefulness of spectrophotometry in chemical and biochemical analyses is abundantly illustrated with references to much recent work.

Part 3 is devoted entirely to the description of available instruments and their merits as tools for the solution of particular problems together with practical instructions in the technique of their use and it can well be summarized by listing the chapter headings—visual spectrophotometry, photographic spectrophotometry, photoelectric spectrophotometry, spectrophotometers with thermal detectors, light sources, cells, standard substances, solvents and diffusing media.

Included also is a bibliography of more than 200 papers and an additional list of 18 books or papers not referred to in the text.

RACHEL FRANKLIN

STRUCTURE AND PROPERTIES OF ALLOYS, by R. M. Brick and Arthur Phillips. Second edition, 485 pp., illustrations, 15 × 23 cm. New York, McGraw-Hill Book Co., 1949. Price, $6.00.

The second edition of this volume of the well-known "Metallurgy and Metallurgical Engineering Series" embodies in an enlarged and improved form the principle underlying the first.

Revision and expansion of the former text, addition of two new chapters (on alloys of magnesium and on corrosion- and heat-resistant alloys), and inclusion of numerous new tabulated and plotted data and illustrative micrographs have resulted in a volume of 485 pages.

The method of giving all pertinent information on composition, treatment and specimen preparation and of including a discussion of the relevant features of the structure in the captions of the individual micrographs is certain to meet with the fullest approval of the users of this book.

The authors set themselves the double task of acquainting the reader with the principal classes of commercial alloys and with the industrial methods of their manufacture, and of providing him with theoretical concepts that would aid him in the interpretation of their structure and properties and of the physical changes induced by technological treatments.

This task is solved with great didactic skill by following the principle of presenting typical structures and properties of alloys in conjunction with the correlated typical equilibrium diagrams, and of arranging the material in the order of increasing complexity of equilibrium structure realized in the several classes of alloys.

At each stage, the presentation of a typical equilibrium diagram and the correlated structures and properties is followed by a discussion of the time-dependent internal processes, either spontaneous or induced by mechanical, chemical, or thermal treatment, by which these structures and properties are modified.

The authors succeed in giving much practical information on pure metals, copper-, lead,-aluminum-, and magnesium-base alloys, two-phase copper alloys, plain-carbon and alloy steels, cast irons, and sintered metal powders, which renders this volume valuable also as a reference book.

The theoretical concepts required for the discussion of the processes of crystallization, diffusion, precipitation, recrystallization, strain-hardening, quench-hardening, and stress relief are presented in a manner apt to kindle the reader's interest in the subject and to induce him to delve more deeply into it.

This reviewer's only regret is that the general excellence of this volume is somewhat marred by what he considers a quite unnecessary laxity of expression in the definitions of some theoretical concepts and in many descriptive parts of the text, all too commonly found in publications in the field of theoretical metallurgy.

OTTO R. SPIES

MATHEMATICS OF CIRCUIT ANALYSIS, by Ernst A. Guillemin. 590 pp., illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1949. Price, $7.50.

The text is designed specifically as a source book to supplement the usual undergraduate engineering mathematics curriculum. It is more appropriate as a textbook for a course in higher mathematics for engineers. No claim is made as to its rigor, rather it is advanced as a

book presenting an engineering viewpoint. The seven chapter headings are: Determinants, Matrices, Linear Transformations, Quadratic Forms, Vector Analysis, Functions of a Complex Variable, and Fourier Series and Integrals. These topics are adequately treated in surprising detail. Exercises are given at the end of each chapter.

The chapter on determinants covers material through Cramer's Rule, the rank of a determinant, and conditions for the existence of solutions of a system of simultaneous linear equations. The chapter treating matrices enables one to find the inverse of a matrix in several ways. It discusses partitioning of matrices and briefly introduces the idea of the latent roots of a matrix. This idea is carried further in the next chapter which commences with vector sets and takes the reader through the Cayley-Hamilton Theorem.

There is good continuity throughout the text. Each chapter lays the necessary groundwork for the material to be presented in the following one. The last three chapters are quite lengthy going into considerable detail. The sixth goes into the standard material in complex function theory including the principle of analytic continuation, Laurent expansion, contour integrals, Riemann surfaces and the linear fractional transformation; and ends with two articles treating stability criteria and physical impedance functions. In the last chapter on Fourier Series and Integrals the author has included a discussion on evalutaion of inverse transforms through complex integration, and approximate evaluation through use of the saddle point method.

The author is an engineer who has written two volumes on communication networks that are well known in their field. Though written by an engineer from his viewpoint, this text deals entirely with advanced mathematical topics.

DONALD B. HOUGHTON

ELECTRICAL TRANSMISSION OF POWER AND SIGNALS, by Edward W. Kimbark. 461 pp., illustrations, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1949. Price, $6.00.

"Electrical Transmission of Power and Signals" fills a long-felt need for a text which treats not alone the transmission of power, audio frequencies and radio frequencies, but which thoroughly deals with the transmission of all three varieties of electrical energy. As the author points out in his introduction, this concept in teaching is not new. However, it is believed that this is the first text to embody this principle. To the student, this book should be of great value, for even in this day of specialization in the electrical engineering field, the practicing engineer cannot totally disregard the transmission of types of electrical energy other than that with which he is primarily concerned. For the graduate engineer, the book is a good reference whether his main interest be power or communications.

Dr. Kimbark's book consists of sixteen chapters and two appendices. The text material opens with line parameters, goes on to steady state phenomena, then to transient phenomena, and finally to lumped parameter circuits. It contains individual chapters on impedance matching, filters, skin effect, and wave guides. At the end of each chapter is an excellent and very complete bibliography, in addition to which are a number of problems. Throughout the text the author presents numerous sample problems to assist in understanding the text material and to demonstrate practical applications of the theoretical material. The appendices contain much valuable information concerning the characteristics of conductors for open-wire power transmission lines and the characteristics of many types of transmission lines for both power and signals.

ROBERT S. GRUBMEYER

THERMODYNAMIC CHARTS FOR COMBUSTION PROCESSES, by H. C. Hottel, G. C. Williams and C. N. Satterfield. Part One—Text, 75 pp., 22 × 28 cm. Part Two—Charts and Tables. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd., 1949. Price, $2.60 and $2.40.

This book, presented in two separately bound sections, will undoubtedly prove to be a most valuable aid to engineers in fields of combustion and power generation. Part one consists of the text which introduces and describes the charts which are bound separately as part

two. As the authors point out several times in the text, the very rapid increase in the utilization of power cycles wherein the products of combustion of fuel and oxidant actually become the working fluid has not been accompanied by adequate data by means of which engineers might calculate or make a reasonable guess as to the performance expected. The compilation of such data is hindered by the difficulty of being able to accurately determine the thermodynamic properties of the endless number of complicated mixtures which might exist during the combustion of a given fuel and oxidant.

The first approach presented is the construction of a "modified-air chart" which is analogous to the Mollier diagram for steam. This chart is applicable in the low temperature regions where gas-law deviations may be important and involves the burning of moderately volatile hydrocarbons in air. The chart presented is for octene, and depicts the properties of both burned and unburned fuel-air mixtures, with the aid of supplementary plots. It can be used as a chart for pure air or as a mixture chart with allowances being made for moisture and combustion. Two illustrative examples involving the use of the chart are given for a Turbocompressor Power Plant and the Diesel Compression-Ignition Cycle. Fundamental data used in constructing the Modified Air Chart are presented.

At higher temperatures where chemical dissociation occurs, the Modified Air Chart is no longer applicable and a series of "Burned Mixture Charts" for several burned mixtures of octene and air are presented. Six of the charts give the thermodynamic properties of burned mixtures of $(CH_2)_x$ and air at higher temperatures (up to 5500° R) for ratios of fuel used to that required for complete combustion, F, of 0.8, 0.9, 1.0, 1.1, 1.2, and 1.5 while the seventh gives the properties of $(CH_{1.631})_x$ corresponding to 50 mole per cent xylene and 50 mole per cent octene (or 35.7 weight per cent benzene in $(CH_2)_x$), for F of 1.5 (50 per cent more fuel than is required for complete combustion.) Many illustrative examples involving the use of these charts are presented including; the throttled Otto Engine Cycle, the supercharged Otto Engine Cycle, Effect of Flame Travel (both at constant volume and with moving piston), Ram Jet, and the Turbocompressor Engine with Tail-Pipe Burner.

The last of four chapters comprising the text is a description of a general method of attack toward the analysis of any power cycle involving the combustion of a fuel and oxidant such that the four elements involved are essentially only carbon, oxygen, hydrogen and nitrogen. This approach is on the basis of the probability that by far the preponderance of combustion cycles in the near future will involve essentially these four elements.

Tables are presented giving equilibrium gas compositions at two pressures, 14.7 psia and 300 psia, for various mixtures involving H_2O, H_2, O, H, O_2, OH, NO, N_2, CO, CO_2, C, at 200 degree intervals over the temperature range 1600–3200° K. In addition, tables of generalized thermodynamic data involving enthalpy, entropy, internal energy and molecular weight are given as a function of chosen values of the atomic ratios, C/O, H/O, and N/O for the same two pressures and over the same temperature range.

The first chapter of the text contains a very clear discussion of the field to which these charts are applicable and a review of previous work in the field. A brief summary of fundamental data is also included for the purpose of quickly preparing the reader, who is assumed to already be familiar with thermodynamic concepts and methods, for the stress which is to be made on the chemical aspect of the problem. Basically, the complexity of the problem of preparing thermodynamic charts for combustion processes is precisely this difficulty in accounting for the effects of the release of chemical energy during the combustion process. This book represents probably the most practical approach to the problem which has appeared to date.

J. T. AGNEW AND W. E. SCOTT

BOOK NOTES

HIGHER ALGEBRA FOR THE UNDERGRADUATE, by Marie J. Weiss. 165 pp., 14 × 22 cm. New York, John Wiley & Sons, Inc., 1949. Price, $3.75.

Intended for students with a background of two years of college mathematics including calculus, this textbook introduces some of the simpler algebraic concepts. Such topics as

groups, rings, fields and matrices have been presented on an equal basis with the theory of equations. Adequate examples and exercises are given for the use of the student.

EXPERIMENTAL PHYSICS FOR COLLEGES, by Walter A. Schneider and Lloyd B. Ham. Revised edition, 442 pp., illustrations, 14 × 21 cm. New York, The Macmillan Co., 1949. Price, $3.80.

The authors have rewritten nearly half of the book in preparing this revised edition. Many new experiments have been added, while some old ones have been dropped. A rearrangement of the chapters has been made emphasizing the fundamental divisions of physics. The authors' primary aim of preparing a text on experimental physics for elementary students, which would be more than a set of laboratory instructions, has been maintained.

ANALYTIC GEOMETRY AND CALCULUS, by Frederic H. Miller. 658 pp., diagrams, 15 × 22 cm. New York, John Wiley & Sons, Inc., 1949. Price, $5.00.

Professor Miller in his most recent textbook has correlated the subjects of plane and solid analytic geometry, differential calculus and integral calculus as a single branch of mathematical analysis. He offers three specific advantages for this treatment, namely, that interest is more readily aroused, that the fundamentals of calculus may be introduced sufficiently early to be of use in other subjects, and that the reconsideration of a specific topic, when new concepts are introduced, serves as a review of basic principles.

Among the features which should be noted are the summaries at the end of each chapter; the appendix, with a list of symbols, formulas and tables; the 3025 exercises; and the treatment given such topics as maxima and minima, conic sections and the representation of loci in polar coordinates.

HYDROLOGY, by C. O. Wisler and E. F. Brater. 419 pp., illustrations, plates, 15 × 22 cm. New York, John Wiley & Sons, Inc., 1949. Price, $6.00.

With the ever recurrent appearance of items in the press concerning water shortages, lowered water tables and the like, it is obvious that a knowledge of hydrology would be useful to many persons. Water is needed not only for drinking purposes, for agriculture, for power, but increasingly in manufacturing processes, and for such new developments as air conditioning. These increased uses have necessitated tapping new sources of supply, re-use of water, and even limitations of some uses in certain areas where the essential needs could not otherwise be met.

Hydrology is a relatively new science which has seen a great increase in knowledge in the last two decades. The present book is intended primarily to serve as a textbook for college and university use, but secondarily in view of the limited material in book form, as a source of reference for anyone concerned with the problems it touches. In their presentation, the authors commence with a brief definition of hydrology and its importance, and follow this with a discussion of the hydrograph, a graphical representation of a stream's fluctuations in flow arranged in chronological order.

Subsequent chapters deal with the drainage basin, precipitation, water losses, infiltration, ground water, runoff, flood and stream-flow records. Each of these topics has been developed extensively with attention both to theoretical and practical considerations. The chapter on ground water by John G. Ferris points out that the supply is not inexhaustible and that it is necessary to achieve fuller use by sound and rational methods of a trained hydrogeologist and hydrogeological engineer.

There is much of interest in this book for the non-hydrologist and it offers a stimulating presentation of the vital problems involved to the student hydrologist.

CURRENT TOPICS

Binac Demonstrated, New Electronic Brain.—The world's second all-electronic automatic computer was demonstrated in Philadelphia recently at the Eckert-Mauchly Computer Corporation by inventors Dr. John W. Mauchly and J. Presper Eckert, Jr. Named BINAC, it was built to order for Northrop Aircraft, Inc. of Hawthorne, California, first private concern to acquire an "electronic brain." BINAC calculates 12,000 times faster than a human being.

The only other computer like it is ENIAC, built by the same men in 1946 for the U. S. Army. BINAC is tiny in comparison with its 30-ton parent. The computing unit stands only 5 ft. high, 4 ft. long and 1 ft. wide and fits in a medium-sized office. It is the first "giant brain" not gigantic in size, and was designed especially for engineering problems.

"In designing today's advanced military aircraft and guided missiles we constantly encounter mathematical problems which cannot be solved in any reasonable period of time by humans working with pencil and paper or ordinary calculating machines," said John K. Northrop, President of Northrop Aircraft, Inc. "BINAC will be of extraordinary value in reducing preliminary design and test time on most research and development projects.

"In the past it has been practical to carry our analysis of a given design only to a certain point, after which costly and often destructive physical tests were necessary.. With this new computer, calculations formerly impossible or impractical of solution can be completed rapidly with savings of hundreds of thousands or possibly even millions of dollars in time and money."

Actually twin computers, BINAC has duplicate arithmetic channels so it can check itself at every step, and two mercury tube "memories." Each twin has only 700 vacuum tubes. ENIAC has 18,000.

The new computer showed its mettle by solving "Poisson's Equation," a typical engineering problem. BINAC spent more than two hours of actual computation to obtain 26 solutions. For *each* solution the computer did 500,000 additions, 200,000 multiplications, and 300,000 transfers of control, all in the space of 5 minutes. A man with an adding machine would have needed years to complete the same job.

The audience also got a chance to test the computer. They were asked to select numbers at random. These were typed on a small keyboard having only eight keys. The BINAC used coded instructions from a magnetic tape to deal with these numbers. It calculated the square and cube roots of all the numbers in the fraction of a second.

For each square or cube root, hundreds of arithmetic operations have to be done by the computer. A human being with a scratch pad can find a square root correct to eight or nine digits in six minutes. With a desk calculator he can do it in two minutes. The BINAC does it in one-sixtieth of a second.

The BINAC operates in the binary system instead of the decimal one. In the binary system, it is required only to distinguish between zero and one. The computer has to convert automatically to binary numbers before beginning calculations and to convert answers back again to decimal form before printing

them out on an electric typewriter. Actually the computer receives and puts out figures in the octal system, from zero to seven, as this converts more easily to binary than the decimal system does. Decimal numbers may be easily expressed using pairs of octal numbers. The computer sorted them in increasing order from the smallest to the largest. This type of "collation sorting" has never before been done by any computer. It is done only for certain problems.

The audience was able to check results as they came out of the BINAC by consulting a familiar computer's handbook known as Barlow's Tables, showing answers to square and cube roots.

During a recent month the Eckert-Mauchly Computer Corporation ran a training school for computer operators in the plant, attended by Northrop Aircraft, Inc. engineers and mathematicians who will run the computer when it arrives in California. A typical computer staff consists of several operators and service engineers, one or two mathematicians to program problems, and typists to prepare magnetic instruction tapes.

The main reason for the BINAC'S smaller size is the mercury memory invented by Mr. Eckert. It replaces about 17,000 vacuum tubes and can store 15,000 binary digits. Electrical pulses representing numbers and instructions are sent through it at a rate of 4 million per second. They are held in the column by being rerouted through it for as long as necessary. The tremendous speed of the mercury memory makes it possible for the computer to handle a great volume of data.

Dr. Mauchly stated emphatically that the BINAC will not "think." It merely follows instructions given to it in the form of simple arithmetic operations.

"It often takes months and even years to bring a new industrial product from the research laboratory to the factory belt-line," he said. "This time can certainly be shortened through the use of computers such as the BINAC. The new era in industrial design forecast when ENIAC began operating, is now here."

A larger, more general-purpose type of computer named UNIVAC is also being constructed by the Eckert-Mauchly Computer Corporation for customers that include the U. S. Bureau of the Census, the Army Map Service, the Air Comptroller's Office, the Prudential Insurance Company of America, and other private customers.

ADDENDA OF USEFUL INFORMATION

Earlier "giant" calculators such as Harvard's Mark I and II, IBM's huge machine in New York, and the Bell Telephone Laboratories relay computers, are not all-electronic.

BINAC and ENIAC, both from Philadelphia, are the pioneers in this field. Other all-electronic digital computers began to be constructed soon after ENIAC was announced. They include Harvard's Mark III, MIT's Whirlwind, both intended for the Navy, RCA's and Princeton University's computer project, MANIAC, and the University of Pennsylvania's EDVAC. The latter was begun by Dr. Mauchly and Mr. Eckert in 1946 before they went into business for themselves.

Dr. Mauchly's interest in electronic computing was first aroused when he was at Ursinus College and noticed the over-whelming amount of data the weather bureaus have to contend with. He decided to hunt for a faster way of solving some of the complicated equations needed by the weatherman to predict weather accurately. His memorandum on creating an electronic computer came to the notice of Captain H. H. Goldstine of the Army's Ballistic Research Laboratory. Dr. Mauchly and Mr. Eckert were then with the Moore School of Electrical Engineering, part of the University of Pennsylvania. A contract was immediately arranged between the University and the U. S. Ordnance Department to develop the type of electronic computer Dr. Mauchly had described. Dr. Mauchly and Mr. Eckert were placed in charge of construction. The result was ENIAC, made public on February 16, 1946. Later that year the two men went into partnership and formed their own company.

There are also a group of analogue computers, some electronic. The first working analogue computer was constructed at MIT in 1930 by Dr. Vannevar Bush. Sometimes called the differential analyzer, this type of machine represents numbers in terms of some physical quantity such as the angle of rotation on a turning shaft. The results come out in graph form drawn by a pencil. The machine cannot achieve the accuracy or speed of a digital electronic computer that represents numbers by separate pulses and gets its answers in actual numbers on a typewriter.

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Standardization of Oil Seals?—The following is taken from a letter written to Dr. Allen, Executive Vice President and Secretary of The Franklin Institute, from E. P. Stahl, oil seal specialist. It is published, with the consent of the writer, in an effort to determine what interest there is in the proposal to standardize oil seal sizes. Suggestions and letters of inquiry relative to the subject may be addressed to Mr. E. P. Stahl, 306 Pierson Ave., Newark, New York.

"I am a bearing technician and an oil seal specialist. I am a strong believer in standardization and simplification. I believe that this is one way American industry can reduce costs in the face of rising material and labor costs.

"Recently I have been advocating the standardization and simplification of unit oil seals for rotating shafts. Published sizes of unit oil seals have reached absurd proportions. The major oil seal manufacturers in this country now list and make from 1200 to 4000 oil seal sizes in 12 to 14 different types. I believe these size lists could be boiled down to 300 to 400 sizes and still have an adequate number of sizes to meet the requirements of industry. What is your opinion on this subject?

"It would be nice if the major oil seal manufacturers in this country would standardize and simplify their oil seal lists to conform to the British standards established and adopted in 1947."

Farms Need Landing Strips.—In areas where spraying or dusting by airplane has become a routine farm service, a farmer or group of farmers can well afford to provide a grassed landing strip that will lead the pilots to quote lower rates for their work. It is more economical to take a smaller and safer load for a nearby strip than to ferry a heavy load a long distance, says Arthur

Gieser of the U. S. Department of Agriculture. Gieser is the experienced chief pilot of the Division of Grasshopper Control in the Bureau of Entomology and Plant Quarantine. He has been flying for 19 years, and for 7 years has been specializing in insect control by means of aircraft. In suggesting that farmers plan for suitable landing strips in each neighborhood where plane service is needed frequently, he points out that the substitution of pasture for cultivated crops on a few level acres would be repaid by the lower rates for dusting or spraying for control of insects, plant diseases, or weeds.

When a pilot drives an airplane at a speed of 100 miles an hour and treats a strip 100 feet wide, he is covering about 20 acres a minute. Gieser uses this simple fact as a base for calculating loads and discharge rates. If the speed is 70 miles an hour and the treated strip is 60 feet wide, then 0.7 times 0.6 equals 0.42, and this fraction of 20 acres, gives 8.4 acres a minute as the area covered. This serves as a basis for determining how many pounds of dust or how many gallons of spray must be discharged each minute to distribute the quantity of insecticide required per acre for the particular job.

Weston Announces Simplified, Budget-Priced Exposure Meter.—Known as the Weston Cadet and designed especially for travelers, casual photographers and those who want a small, easy-to-use meter for everyday use, a precise new exposure meter has been announced by the Weston Electrical Instrument Corporation, Newark, N. J. It lists at $21.50.

Though small enough to fit into vest pocket or purse, the Cadet is equipped with the famous Weston instrument movement and Photronic Cell, and gives accurate shutter and diaphragm settings for all general amateur photography with either still or motion picture cameras, and for both black-and-white and color film.

The Weston Cadet can be used for measuring either reflected or incident light. A transluscent light collector, pivoted on the back of the meter, converts the Cadet from a reflected light to an incident light meter in an instant.

And the Weston Cadet is easy to use—simply take a light reading in the usual manner, set the light value over the emulsion speed by turning a convenient knurled button, and read the correct camera settings.

Atomic Energy Commission Starts Trial Program to Make Technological Information Available to American Industry.—A trial program for examining selected declassifiable technological information in the field of metallurgy with a view to determining its possible value to American industry has been inaugurated by the Atomic Energy Commission. To assist in developing the program, a temporary advisory committee of representatives of professional societies and the business press has been appointed.

The purpose of the program is to determine the possibility of providing to industry information about pumps, blowers, valves, techniques of handling metals, and other metallurgical data which will be of immediate value to industry. The trial program will determine whether such selected information can be gathered, screened, and declassified for release in a way which will not reveal the specific relevance of the information to the atomic energy program.

The setting up of the advisory committee is the first step. This group will recommend members for a small working party of engineers, representatives

of professional societies, and members of the business press in the field of metallurgy who will receive full security clearance. After the working group members are cleared, the Commission will make available for examination by the working party metallurgical information which may be declassifiable.

From the information made available to it, the working party will recommend to the Commission those portions which it believes should be considered for declassification because of their usefulness to American industry and technology. The Commission will exercise, of course, the final responsibility for declassifying any recommended material, taking into account the considerations against declassification as well as those favoring declassification.

Any information which the Commission may actually declassify would be made available for publication by established engineering and industrial journals in the field of metallurgy. If the trial program in metallurgy proves effective, the Commission will consider the application of similar procedures to other fields of technological and industrial information.

An Electrical Bridge De-icer (*Electrical Engineering*, Vol. 68, No. 8).—Electric current, flowing in cables buried below the surface of the concrete roadway, will keep Brooklyn Bridge free of snow and ice in future winters, if New York authorities adopt the proposal of Robin Beach, head of Robin Beach Engineers Associated, Brooklyn, N. Y. The renovation of the famed Manhattan-Brooklyn artery, so that it will accommodate six lanes of traffic, now is being planned. According to Mr. Beach, electric heat can remove snow and ice from the bridge as fast as it appears on the road surface. Therefore, he suggests that the installation of heating cable be a part of the program.

It is reported that the bridge's traffic lanes will be surfaced with steel-grid-reinforced concrete. Concrete, of course, is a relatively poor conductor of heat, but the steel surface grid would provide an efficient metallic conducting network for distributing the heat right at the roadway surface, where it is desired.

Lead-covered insulated resistance wire would be the heating cable used. It has been utilized successfully in the past for the purpose of clearing eaves and leaders of buildings, sidewalks, and other surfaces of ice and snow.

This heating cable would be embedded in the concrete roadway, and would be connected to operate on 220 or 440 volts. The higher voltage is thought to be more economical, however. The heating elements of the cable can carry as high a load as 25 amperes.

Power cables for energizing the resistance wire could be run along the sides of the bridge, from which connection would be made to the heating cable through appropriate weatherproof outlets. Protective fuse cut-outs similar to those found in conventional home or industrial circuits would be a part of the equipment.

The continuous warming of concrete surface with heating cable would require the application of electric power of the order of 20 to 40 watts per square foot of roadway. Using the maximum value of 40 watts per square foot, the six 10-ft. traffic lanes for the 6,000-ft. length of the bridge plus the terminal approaches would necessitate a power expenditure of 16,000 kw.

Assuming an electric rate of one cent per kilowatt hour, the cost of heating the entire bridge, including traffic lanes and approaches, would amount to

roughly $1.60 per hour. When the temperature is a little below the freezing point, 20 watts per square foot might be adequate, thus halving the cost.

In operation, the use of the electric heating would be required for a few days per year. The instantaneous removal of the snow as it falls would require only a fraction of the expense now incurred with manual labor.

Portable Atom Sorter (*Instrument Practice*, Vol. 3, No. 9).—Research representatives of the leading American oil companies saw recently for the first time a new portable "atom sorting" device, an accurate, high-speed gas analyser for oil refining and prospecting.

The analysing machine was demonstrated at the Westinghouse Research Laboratories by Dr. E. U. Condon, one of the leaders of the laboratory, and Dr. J. A. Hipple, research physicist who developed the device and named it a "portable mass spectrometer," or "atom sorter."

The "atom sorter" can sort out by weight the molecules and atoms which are the building blocks of all matter. It can quickly answer questions about intricate combinations of gases which are very difficult or impossible by ordinary chemical methods.

With a little further development by the oil laboratories, the "atom sorter" could probably improve the quality of refinery products by keeping a constant check on the separation and combination of gases. There are possibilities, too, that the instrument can discover new oil deposits by analysing soil gases.

Dr. Hipple, who designed the device, after building a room-sized mass spectrometer, explained that the new instrument has been made compact and placed on wheels so it can easily be rolled from one job to another. Other uses include the analysis of gases for the heat treating and hardening of steel and the tracing of carbon and other elements in animal bodies.

America's First Zoo (*DuPont Magazine*, Vol. 43, No. 4).—Keeping pace with an age of television and supersonic speeds, despite a history that goes back to a yesterday of horse-drawn trolleys and high-button shoes—that's the story of America's oldest zoo, the Philadelphia Zoological Garden.

Although 1949 marks the Diamond Jubilee of this famous institution, it has not been allowed to fall behind the times. There are more than 1500 specimens here today, in contrast with the 282 animals exhibited on the opening day, July 1, 1874. Besides boasting many modern buildings and some of the newest methods of exhibiting animals, it is one of two zoological parks in the country that has its own staff photographer. And, as far as we know, the Philadelphia Zoo is the only one employing a woman staff photographer.

When this institution first came into being, its guide books and cage signs were illustrated with old-fashioned drawings. But with the manufacture of modern photographic products, the Garden's publications were filled with pictures, and many of its cage signs were embellished with colored photos of the animals.

Isabelle dePeyster Hunt began her work as staff photographer in September 1942. Since then many fine animal shots have won her a respected place in her field. The problems she encounters in "shooting" the mammals, birds and reptiles are very unusual, for they require patience and understanding demanded by few other jobs. Monkeys, hippos and tigers are not easy sub-

jects; they won't sit still and pose for their portraits. However, Du Pont products—"Defender" photographic films and papers—help make her "shooting" and darkroom work easier.

When the modern Tropical Room in the Reptile House was designed, it presented a new problem. An entirely different type of sign was needed—one that could be easily illuminated from the rear, could be easily read, and would show in natural colors the reptiles in each cage. This would be helpful in distinguishing one species from another when several were in the same pen. Du Pont solved this problem for Miss Hunt with "Adlux" photographic film for transparencies. She printed her negatives on this material, then colored the pictures with photographic oil paint. The descriptive text was printed by the Zoo's hand press, and a new and distinctive sign style had been created.

In the Tropical Room the snakes, frogs, turtles and lizards are displayed in well-lighted cages, behind glass, with backgrounds simulating natural habitats. The "Adlux" signs, illuminated from the rear, are set above each exhibit. The public corridor is dimly lighted, and the result is one of the most spectacular displays in the Garden.

The Students' Spectrometer (*Instrument Practice*, Vol. 3, No. 10).—This new addition to the Watts' range of spectrometers has been designed specifically for educational use.

For this reason, a considerable amount of thought has been given during its development to both questions of economy and durability. The design is simple, incorporating the minimum refinements compatible with good training. Nevertheless, the instrument is accurate to within the limits necessary for the work it will be called upon to perform, and its construction is of a type successfully to withstand really hard wear. All optical and mechanical adjustments are makers' adjustments, not accessible to inexperienced users.

A single divided circle is employed to measure the rotation of both telescope and prism table. The circle is graduated to single degrees and opposite verniers give readings to 2 minutes.

The circle normally rotates with the telescope while the verniers, which are engraved on a single ring moving inside the circle annulus, rotate with the prism table. Either may be unclamped for independent rotation.

It has the conventional 3-screw levelling type of table, 2.5 in. in diameter. It is adjustable for height and the table top has independent rotation for adjustment purposes.

Ring focusing is provided on the telescope and collimator, each having an aperture of 0.7 in. and focal length of 4 in. A Gauss eyepiece is fitted to the telescope.

The collimator slit has unilateral adjustment, the moving jaw being operated, through an internal cam, by a knurled head surrounding the slit. This arrangement gives a comfortable hand-hold with good control over the movement. Spring pressure automatically returns the jaw once the slit is closed, to prevent accidental damage to the slit edges.

The manufacturer is Hilger & Watts, Ltd., London.

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